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THE SUBSTANCE OF MANAGEMENT *

BY

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Many years ago, a young engineer went to see Charles Day for advice. He was, as might be expected, nervously diffident about approaching a man of Mr. Day's stature in the community. Mr. Day not only dispelled the young man's first reluctance, but also gave him, from a profound store of experience and wisdom, an appreciation of broad and fundamental values which served and guided him in every subsequent step of his career, including this evening which we are spending together.

It is most happy indeed that these yearly gatherings have been made possible to preserve the wisdom and ideals of a man who, himself, could have made such a great contribution if he were still among us today.

I feel again tonight some of the same reluctances of that evening many years ago; for our discussion is, so to speak, a personal accounting on my part regarding the use which I have been able to make of Mr. Day's example and precepts. I can only report to you that the precepts and example given so long ago have proven more extensive and inspiring than any young engineer had any right to expect.

It is but fair to forewarn this distinguished group that this lecture will not, and indeed cannot, live up to the broad scope of its title. I had originally more correctly called it "Some Observations on the Substance of Management," but the experts said that this was altogether too general, and advised the shorter description as possibly more in-

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triguing. Actually, I hope to touch upon the subject in terms of a sub-title: "Some Comments on the Education of an Engineer."

Many years ago, I was for a time a thorough reader of the "Atlantic Monthly." I was living abroad at the moment and the "Atlantic" not only helped to maintain the proper intellectual standards, but also happened to be about the only magazine on sale locally. One article and its repercussions have always stuck in my mind—it was titled "An Engineer Looks at Medicine." He not only looked at it; he took it apart critically and dogmatically, especially as regarded homeopathy. Among the letter-writers who responded was one who said, according to my recollection, "Dear Sirs—I, too, as a doctor could look at engineering, but I know my limitations.—Very truly yours, etc."

Those were the days when engineers, with general consent and approval, took over a lot of territory. Besides the recognized fields of engineering, we had Efficiency Engineers, Human Engineers, and others who barely avoided invading the professional fields of law and medicine. Many of these so-called engineering activities have since gone to their long home. But not all—I have just read an article titled, "Nutritional Engineering." The subject matter was interesting and encouraging, but did not to my mind establish dietetics as an engineering rather than a medical field—I may be wrong, and if anyone wishes to explore this point further, the article appears in the JOURNAL of this institute, Vol. 238, No. 2, August, 1944.

This brings us to the subject which we are to consider together this evening; to wit, some part at least, of the substance of management as seen by one engineer; and the same engineer's tentative comments on management requisites of moment. In the field of management, engineering has a very proper place; for an engineer, by definition, is among other things, "a skillful manager"; and management, by definition, is among other things, "the judicious use of means to accomplish anything." But to my mind, an engineer is not *ipso facto* a skillful manager; he becomes skillful only by *judiciously* using means to accomplish the objectives of management. And the objectives of management, in this industrial stronghold of an ancient mechanical society, are not merely the accomplishment of a narrow "anything," but rather the broad and very important accomplishment of a great many fundamental objectives demanded by a complex society. Mr. Morris L. Cooke in the first Charles Day Lecture five years ago, and Mr. William Meinel in last year's lecture, dealt profoundly with this same general theme.

To my way of thinking, the real substance or stuff of management is the creative ability of managers to sense and to respond successfully and continuously to the challenges which confront them in the broad area affected by their management. At first blush, this may appear to be a deceptively vague and obvious generalization. It takes for granted, as it must, technical proficiency. We have spent twenty or forty years becoming technically proficient, without giving too much

thought to the question—"For what purpose?" Our creative and successful response to some challenges has been extraordinary—to other challenges less so, as the economic and social upheaval culminating in two devastating holocausts will attest. Sometimes the successful response to our challenge has, in effect, diminished our ability to respond to the next, and very different, challenge. This is not due to enervation or indifference, but rather to the historically recorded fact that the achievement of great success turns the path away from greater successes. Thousands of years ago, the shark was, as he continues to be, such a successful fish that he swam out to sea with great speed and eclat. He left behind a small, unsuccessful fish with puny flippers who climbed out of the water and started the evolution towards higher forms, including ourselves.

But let us not despair; creativeness and vigor burn brightly with us, although perhaps not in a self-replenishing fashion.

To give point and definition to this theme, I intend to draw upon a few experiences in Mexico, where I have spent the last three years in managerial work. Mexico is a beautiful and vivid country, which has a peculiar way of attaching itself to one. It also, in its past and present history, presents dramatically some very illuminating points on cause and effect. In Mexico, causes produce effects with little delay, and with even less benefit of the "shock absorbers" which soften and sometimes disguise the impact in a highly organized society like ours.

MANAGERIAL INSIGHT

At the turn of this century, Mexico was in the midst of a period unique in its history since the conquest. It was passing through thirty years of uninterrupted peace. Foreign capital was welcomed; basic economic development strode forward, railroads were built and run on time, the arts flourished in their particular way. In superficial material terms, it was a golden age in Mexico, and would have been so regarded in any other country. The man and group responsible for this happy state of affairs were the president, General Diaz, and a coterie of gifted administrators called *los científicos*—the scientific ones. These men were early and worthy exemplars and students of "scientific management." Whatever else may be said of Diaz and his *científicos*, their administrative and technical abilities have been generally acknowledged.

Because he was a dictator and because he and his *científicos* failed to sense the essence of the internal Mexican challenge, the Diaz regime bred the Mexican revolution which not only ended that regime in 1910 but plunged an orderly country into thirty years of fermentation, which is a tactful way of referring to Mexico's travail.

The revolutionaries who upset the Diaz regime had in mind three purposes which were not unreasonable, and about which something useful might have been worked out:—

1. They wanted an effective ballot which would make it impossible for any group to perpetuate itself against the wishes of the people.
2. They wanted the Mexican government to stop being a "mother to foreign interests and a stepmother to Mexico."
3. They wanted the benefits of Mexico's progress to go to the many instead of the few.

Diaz and his *científicos*, apparently secure in their position, at first made the efforts of the revolutionaries appear ludicrous; but within a year, the revolutionary cloud, at first no larger than a man's hand, had covered the country and Diaz with his associates were completely and irrevocably liquidated. We may well inquire if this development had to be inevitable. I think not: for Diaz himself was once a revolutionary. It was not necessary for him to lose touch with his countrymen and their aspirations. His success, of a kind that we can appreciate, carried him out to sea; and although he competently exercised his superb talents, the area and objectives were unacceptable to the millions of Mexicans who groped for something else.

My point here is that the managers, if you please, failed to sense the challenge of the moment in all its importance and implications. To them, the impossible and fantastic happened. The essential management ingredient of insight was lacking in them.

While we do not often think of management insight, it happens to be one of the factors which is functional to management, observable in action, and predictable in the individual manager. The engineers, in their millions of words on "scientific management" have generally missed this one; those that recognized and understood it have been men like Charles Day.

MANAGERIAL ELAN

The revolution had, and continues to have, a terrific impact on management in Mexico. It is perhaps obvious that management prestige suffered, and that revolutionary objectives, especially as regards the worker, were strongly and firmly established. Since returning to this country, I have encountered great interest and incredulous wonderment regarding the conditions under which management in Mexico must strive towards its goal.

Managers up here would consider these conditions novel and somewhat restrictive, and rightly so. Under the revolutionary Federal Labor Law of 1932, which covers everything imaginable touching upon labor, including the alcoholic content of intoxicating liquors, the following conditions, among others, are imposed:

1. The employer must pay to any worker released a dismissal compensation of three months plus twenty days salary for every year of service, except in an exceedingly limited group of discharges for cause.

2. The employer can shut his plant down only with government approval, regardless of the duration of the shut-down. A legal shut-down does not terminate the economic liability of the employer to his employees.

   In our company, we suspended taking orders for one of our departments because of high costs. For a period of four months the entire department work force drew full salaries and reported at the plant to read newspapers and so forth. Finally work was resumed with a new and somewhat better wage scale.

   The general effect of this feature of the law is to give the employer full initiative in expanding his activities, and to the government and unions almost complete initiative as regards the curtailment or suspension of activities.

3. In the event of a legal strike (and for practical purposes all strikes have a way of being legal) the employer is liable for payment of all salaries for the duration of the strike.

   Our company underwent a three-week strike over the renewal of our labor contract. The strike was launched amidst fire-works, music by strolling serenaders, and fair quantities of *pulque*[2] as the red banner was stretched across the yard entrances. The workers established their 24-hour vigil; because if the company could succeed in removing a shipment from the plant, the status of the strike would have automatically been altered. Access to the plant except by the Union safety committee was prohibited. There was a general air of "cops and robbers." When the strike ended, again with fire-works and music, the Company not only paid strikers' wages for the three weeks, at the new scale of course, but also a lump, unitemized sum for the Union strike expenses (telegrams, fire-works, music, *pulque* and miscellaneous).

Aside from the basic provisions of the Federal Labor Law, collective labor contracts can and do add additional restrictions. In the voluminous contract between our company and the Miners' Union, many burdensome clauses appeared, of which the two following are fairly simple and typical:

1. Time lost on account of accident is paid at full earning including all production premiums, starting from the moment of accident and continuing to the moment of return. Thus, a worker loses nothing financially as a result of a lost time accident. In some instances, this might be considered as equitable. But it is possible, and in fact often happens, that workers "arrange" for convenient and not too serious mishaps having previously established high earnings as a basis for accident compensation. And it is unusually difficult for management to police malingering.

[2] Fermented cactus juice; hence, cactus in one of its lower forms.

2. The Union has the right to complain of management, and demand the removal of management representatives, directors excluded. I know of a case where, in another company, the union demanded from the general manager the removal of the medical director. Against advice, the manager acceded. The precedent having been established, a few months later the union demanded, and obtained, the removal of the manager himself.

These five examples will suffice to suggest that managers in Mexico must have a fair amount of resiliency. In fact, management in Mexico or anywhere else must have a *vital impulse towards its job*. Some people call this impulse drive; but I prefer the connotation of the word elan, which has happily become part of the English language. "Drive" implies vigorous pressure, and this is good as far as it goes, which is not far enough. It is apt to be construed in its more physical sense.

To be sure, managers abundantly need physical vigor, and in this country especially, the constant doer commands admiration. He commands my admiration as long as he pushes his problem forward, and not over. By carefully nursing an egg along at the proper heat for three weeks, you can hatch a chicken if all goes well. If you want to speed up the process at higher temperatures, you can get a hard-boiled egg in about twenty minutes. Sometimes drive boils eggs; elan hatches them, if possible. Artemus Ward tells the story of an amateur pyrotechnist whose elan finally produced a display of fireworks which was stupendous. His drive also resulted in blowing all his fingers off.

Can elan be effective under the restrictive conditions which I have described? Yes, for management can adapt itself to the conditions under which it must operate, developing the ingenuity and fore-sightedness required. In the case of lost time accidents, the record of some of the company's departments was deplorable, especially in departments which presented no special hazards. But in other departments, some with dangerous exposure, the record was excellent and altogether comparable with U. S. experience. The difference?—management effectiveness. Again, the practical effect of the management discipline clause was nil, and for the same reason. The most acceptable managers were those who were strict, fair and competent and possessed elan; the least acceptable and most under fire were those who lacked management impulse, conviction and competence.

Elan is both physical and emotional. Like insight, it is functionally essential to management; it is observable; and it is predictable in the individual. As a fundamental element in management, it has perhaps not received its qualitative and quantitative due from the engineers.

SOCIAL SKILLS

Some of you must be wondering by this time how managers in Mexico solve problems, even when they are generously endowed with

some unusual qualifications. How, for example, do strikes get settled when there appears to be no particular inducement for the worker to get back to work? The answer is, of course, that people everywhere are, in the last analysis, people, and respond to devices which recognize this. A high degree of social skill is required; for besides the difficulties outlined above, the workers' leaders are in many cases revolutionary characters. Table-thumping becomes a luxury beyond the margin of diminishing returns.

In our strike meetings, progress usually took place between four and seven o'clock in the morning, when resistance was low. We also used some kind of pill which restored vigor and acuity when these lagged. And we talked and bargained, and kept on talking and bargaining. But above all, we assembled our facts, threw emotions out of the window, and used every social skill involved in face-to-face dealing. I will always remember vividly the skill of Mexicans to interpret a gesture and to catch a meaning. Up here, we take for granted that there are several ways of saying the same thing: in Mexico, there is only one way of saying something. When you say it some other way, it means something else, and sometimes the difference is major.

Consequently, the development of social skill and sensitivity to others becomes an art which is useful wherever people deal with each other. Flat-footed statements like "it stands to reason" are quickly discarded. You size up the other fellow, and persuade, cajole, charge, retire, pull out stops, push them in again, and remember all the time that you want to settle for 15 per cent increase in a two-year contract, which we did.

I am not implying that social skill is a substitute for facts and figures. Rather, I am making the very important point that without social skill, facts and figures go to their long statistical rest.

Mr. Meinel last year touched importantly on this point, and suggested how managers might usefully improve themselves in this area. One need not be born with high social skills; they can be developed, given a reasonable base. But the acquisition of high skills is not easy; one does not learn how to play a piano from handbooks, and I suggest that the human being is a fairly complex instrument.

EMOTIONAL STABLIITY

Emotional stability, or at least emotional control, should accompany social skills. One might easily and rightly imagine that the atmosphere described above encourages all manner of conspirational and emotional situations. First of all, the art of veiled and unveiled insult, along with other forms of irritations, is effectively and purposefully cultivated. Fantastic edifices of misconstruction are built on basically forthright declarations. Fifth columns exist like wheels within wheels; it is sometimes very difficult to know just where or why they are headed, and a

certain amount of traffic control is essential. Mexico is a great place for meetings under the old eucalyptus tree at midnight.

All these goings-on require a sense of humor; in fact, Mexicans possess this sense to a high degree, and it is expected of managers. Humor is essential to keep everything on a game level; otherwise the relations become seriously dangerous. Inherently the situations are serious enough without obstructing the flow of effective human dealing with emotional blocks and distorted sense of values.

While the demands upon social skills and emotional stability might be somewhat more urgent in Mexico than here, we should not ignore the growing fundamental need for these same qualities in managers wherever they exercise their responsibilities today. There is nothing vague or hazy about the importance of these essential qualifications—without them, other managerial skills are frustrated.

THE ART OF MANAGEMENT

By this time, you will feel that the substance of management relates closely to what is often called, in an off-handed way, the art of management. Perhaps so, but some interesting things can be said of art. Art is both skill and the thing for which the skill is used. Furthermore, Art with a capital A has been widely recognized as the most accurate index of the rise, vigor and decline of civilized societies. We are perhaps justified in considering that some of the creative urge which expressed itself in painting, sculpture, architecture and music in other years, now expresses itself in management. I say this because in our highly industrialized society, Art appears in many industrial forms not previously encountered.

As regards the decline of Art in recorded history, the skills were not lost, except in one or two cases (Mexico being one) where the destruction of skills was planned and deliberately executed. But Art can lose, and has lost in times past, its substance. It can cease to have meaning and relevance. It can lose its insight and vital impulse, and deteriorate into meaningless forms which lose touch with people and their aspirations.

So it is with management. We have gained rather than lost ground in skills and techniques. It is not quite clear, as regards both Art and Management, that insight and impulse have kept the same pace. There has been a good bit of honest groping in this respect. Sometimes when I hear a bit of modern cacophony or look at a "mobile," I wonder if other people feel as bewildered as I do with the high degree of skill and the rather complete lack of meaning, at least to me.

Our driving concern is with the substance: this has always been so. And of particular concern is the substance of management, for modern management is certainly one of our greatest contributions and means of self-expression, from which hundreds of millions of people take meaning.

GRAPHICAL ANALYSIS OF IMPACT OF BARS STRESSED ABOVE THE ELASTIC RANGE*

BY

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Part II[2]

II. IMPACT IN THE STRESS RANGE ABOVE THE ELASTIC LIMIT

As it was discussed before, the materials under discussion here have a stress-strain relationship such, that the elastic modulus $dp/d\epsilon = E_0$ is constant below a certain stress value which is called the elastic limit; at this stress the value of E_0 undergoes a sudden decrease to a new E_1 value, which at increasing stress values decreases gradually still further. It has been found however, that on unloading the initial E_0 elastic modulus is valid, and that, furthermore, once the material is stressed to a p_i value above the elastic limit, thereby its new elastic limit is raised to the p_i value, that is, on the reapplication of stress the material will follow the E_0 line up till that p_i value is attained.

In accordance with these characteristics, also the velocity of propagation a, and the wave factor E/a, undergo first a sudden, then a gradual decrease in the stress range above the elastic limit. The change of the velocity of propagation with stress is illustrated in Fig. 15. The derivation of the $E = f(p)$, $a = f(p)$, $E/a = f(p)$ relationships from the basic $\epsilon = f(p)$ curve has been already given (Fig. 4), and is repeated here for annealed copper, at larger scale, Fig. 16. By integration of the a/E curve according to stress, the $\int dv = \int (a/E)dp$ curve is obtained, which has the characteristic that for any p value its slope is equal to the wave factor E/a for that p value. The integration can be performed either by computation or by graphical construction, in the known manner.

With the aid of the $\int dv$ curve in the v–p diagram the change of state in the bar can be followed in a manner similar to that explained in the preceding examples for elastic impact. The differences of the procedures may be listed as follows:

1. In the stress range below the elastic limit, that is, for $p_i < p_e$ the velocity of propagation a_i, and the wave factor L_i/a_i are constants:

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[2] Part I appeared in JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 248, No. 1, July, 1949, p. 15.

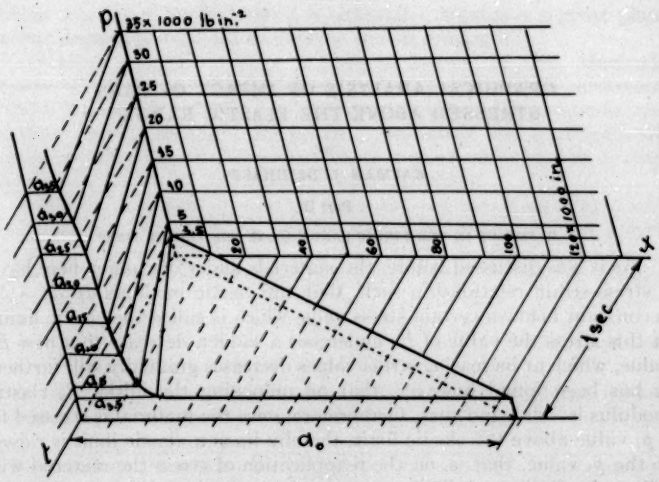

FIG. 15(*a*). Stereogram of stress for instantaneous change of stress, showing variation of velocity of propagation as a function of stress (for annealed copper, according to Figs. 4 and 16).

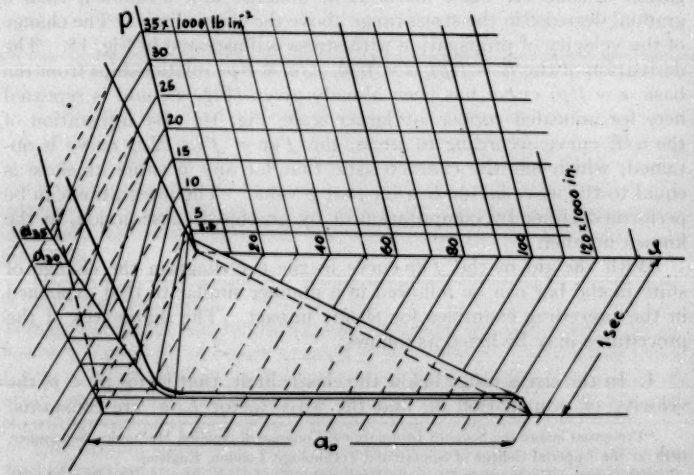

FIG. 15(*b*). Stereogram of stress for gradual change of stress ($p = p't$), showing variation of velocity of propagation as a function of stress. Gradient of stress is shown for the $t = 1$ time (for annealed copper, according to Figs. 4 and 16).

for $p_i < p_e$:

$$a_i = a_1 = \tan \varphi_1; \qquad \left(\frac{E}{a}\right)_i = \frac{E_1}{a_1} = \tan \alpha_1.$$

2. At the elastic limit, $p_i = p_e$, both the velocity of propagation, and the wave factor, undergo a sudden decrease to new values: for $p_i = p_e$:

$$a_i = a_2 = \tan \varphi_2; \qquad \left(\frac{E}{a}\right)_i = \frac{E_2}{a_2} = \tan \alpha_2.$$

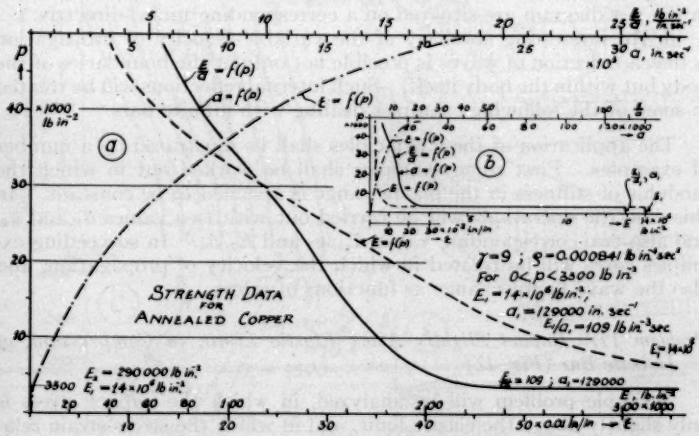

FIG. 16. The significant elastic and plastic relationships as derived from the stress-strain curve (for annealed copper, according to White and Griffis, ref. 34).

3. Above the elastic limit, $p_i > p_e$, the velocity of propagation, and the wave factor, change gradually, in a manner corresponding to the change of the square root elastic modulus for $p_i > p_e$:

$$a_i = \sqrt{\frac{E_i}{\rho}} = \tan \varphi_i; \qquad \left(\frac{E}{a}\right)_i = \sqrt{E_i \rho} = \tan \alpha_i.$$

The nature of these relationships for annealed copper is illustrated in Fig. 16.

4. The velocity of propagation and the wave factor, are, for any stress value, proportional:

$$a_i = \sqrt{\frac{E_i}{\rho}}; \qquad \frac{E_i}{a_i} = \sqrt{E_i \rho};$$

hence

$$\frac{E_i/a_i}{a_i} = \rho.$$

(The density was assumed to be constant.) Therefore, tan φ_i is proportional to tan α_1, and by suitable choice of the t, x, v, and p scales can be made equal (which facilitates the drafting work in the graphical construction).

5. It is to be noted, that if in the t–x diagram two adjacent domains are separated by a tan φ_i disturbance line, then the corresponding states in the p–v diagram are situated on a corresponding tan α_i directrix.

6. An interesting corollary of the variable velocity of propagation is that a reflection of waves is possible not only at the boundaries of the body but within the body itself. Such internal reflections will be treated in some of the following examples dealing with infinite bars.

The application of these principles shall be illustrated by a number of examples. First some examples shall be worked out in which the modulus of stiffness in the plastic range is assumed to be constant. In this case the operations will be carried out with two values a_1 and a_2, and also two corresponding values E_1/a_1 and E_2/a_2. In succeeding examples cases will be treated in which the velocity of propagation, and also the wave factor change as functions of stress.

Problem 11. Impact Slightly Above Elastic Limit, in Compression, of Infinite Bar (Fig. 17)

A simple problem will be analyzed, in which the impact stress is only slightly above the elastic limit, and in which the stress-strain relation above the elastic limit can be assumed to be linear. For the sake of clarity a definite material, annealed copper, is assumed, the properties of which are given in Fig. 16.

The impact at velocity v_3, is assumed to last $T = 1$ second; its intensity is 4000 lb. in.^{2} (elastic limit is 3500 lb. in.^{2}) corresponding to an impact velocity $v_3 = 63$ in. sec.$^{-1}$.

At the onset of impact two waves start: one with state 2 corresponding to the elastic limit, and propagated with velocity a_1, and the other with state 3, corresponding to the velocity of impact v_3, propagated with the slower velocity a_2 valid for the plastic range. The t–x domains which these states characterize are given in Fig. 17(b) and (b'). The bar length in domain 2 undergoes only elastic deformation, the bar length in domain 3 undergoes also a plastic deformation. At the termination of the impact period T the unloading wave is initiated, having state 4, which is propagated at velocity a_1 and overtakes the wave 3 (which is propagated at the slower velocity a_2) at the instant t_1, at which a length L_D of the bar has been plastically deformed. This wave is

reflected back toward the bar end as state 5, where it arrives at instant t_2 whereupon the bar resumes its initial state 6 (= state 1).

The displacement of the cross sections, and the location diagram are given by Fig. 17(*b*) and (*b'*), and the diagram of state by Fig. 17(*c*),

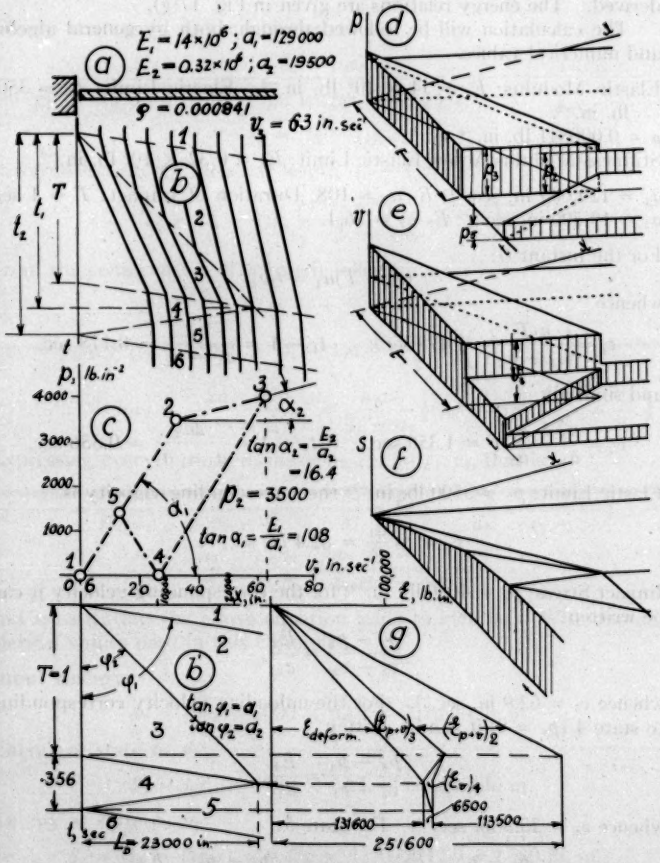

FIG. 17. Impact slightly above elastic limit, in compression, bar of infinite length.

(*a*) Schematic arrangement.
(*b*) Displacement of cross sections.
(*b'*) Location diagram.
(*c*) Diagram of state.
(*d*) Stereogram of stress.
(*e*) Stereogram of velocity.
(*f*) Stereogram of displacement.
(*g*) History of energy relations.

which can be readily followed on the basis of the information given in the foregoing examples for elastic impact. From Fig. 17(*b'*) and (*c*) the stereograms of stress and velocity, Fig. 17(*d*) and (*e*) can be readily constructed, and from these the stereogram of displacement, Fig. 17(*f*), derived. The energy relations are given in Fig. 17(*g*).

The calculation will be followed through, both by general algebra and numerical values.

Elastic Modulus: $E_1 = 14 \times 10^6$ lb. in.$^{-2}$. Elastic Limit: $p_2 = 3500$ lb. in.$^{-2}$.
$\rho = 0.000841$ lb. in.$^{-4}$ sec.^{2}.
Stiffness Modulus Above Elastic Limit: $E_2 = 0.32 \times 10^6$ lb. in.$^{-2}$.

$a_1 = 129{,}000$ in. sec.$^{-1}$; $E_1/a_1 = .108$; Duration of Impact: $T = 1$ sec.
$a_2 = 19{,}500$ in. sec.$^{-1}$; $E_2/a_2 = 16.4$.

For the instant t_1:

$$(t_1 - T)a_1 = t_1 a_2,$$

whence

$$t_1 = \frac{a_1 T}{a_1 - a_2} = 1.178 \text{ sec.}; \qquad t_1 - 1 = \frac{a_2}{a_1 - a_2} = 0.178 \text{ sec.}$$

and similarly

$$t_2 = \frac{a_1 + a_2}{a_1 - a_2} T = 1.356 \text{ sec.}; \qquad t_2 - 1 = \frac{2a_2}{a_1 - a_2} = 0.356 \text{ sec.}$$

Elastic Limit: $p_2 = 3500$ lb. in.$^{-2}$; the corresponding velocity is:

$$v_2 = p_2 \frac{a_1}{E_1} = 32.4 \text{ in. sec.}^{-1}.$$

Impact Stress: $p_3 = 4000$ lb. in.$^{-2}$; for the corresponding velocity it can be written:

$$\frac{p_3 - p_2}{v_3 - v_2} = \frac{E_2}{a_2},$$

whence $v_3 = 62.9$ in. sec.$^{-1}$. For the unloading velocity corresponding to state 4 ($p_4 = 0$) it can be written

$$\frac{p_3 - p_4}{v_3 - v_4} = \frac{E_1}{a_1},$$

whence $v_4 = 25.8$ in. sec.$^{-1}$. For state 5:

$$\frac{p_5 - p_4}{v_4 - v_5} = \frac{E_1}{a_1}, \qquad \text{and} \qquad \frac{p_5 - p_1}{v_5 - v_1} = \frac{E_1}{a_1},$$

whence

$$v_5 = \frac{v_4}{2} = 12.9 \text{ in. sec.}^{-1} \qquad \text{and} \qquad p_5 = 1390 \text{ lb. in.}^{-2}.$$

The energy relations can be expressed, in general terms:
Input energy

$$\mathcal{E}_1 = p_3 v_3 T = p_3 v_3.$$

This energy is distributed and applied as follows:

Energy at state p_2, v_2, for a bar length a_1:

$$\mathcal{E}_2 = p_2 v_2.$$

Energy at state p_5, v_5, for a bar length $(t_2 - T)a_1$.

$$\mathcal{E}_3 = (t_2 - 1) p_5 v_5.$$

Deformation energy for a bar length $(t_1 - 1)a_1$:

$$\mathcal{E}_4 = (t_1 - 1) a_1 \frac{p_3^2 - p_1^2}{2} \left(\frac{1}{E_2} - \frac{1}{E_1} \right).$$

From the conservation of energy it follows:

$$\mathcal{E}_1 = \mathcal{E}_2 + \mathcal{E}_3 + \mathcal{E}_4,$$

$$p_3 v_3 = p_2 v_2 + (t_2 - 1) p_5 v_5 + (t_1 - 1) a_1 \frac{p_3^2 - p_2^2}{2} \left(\frac{1}{E_2} - \frac{1}{E_1} \right)$$

$$= p_2 v_2 + \frac{2a_2}{a_1 - a_2} \frac{E_1}{a_1} v_5^2 + \frac{a_1 a_2}{a_1 - a_2} \tfrac{1}{2} (p_3^2 - p_2^2) \left(\frac{1}{E_2} - \frac{1}{E_1} \right)$$

Expressing every term in terms of p_2, v_2 and p_3, v_3, that is,

$$\frac{a_1}{a_2} = \frac{E_1/a_1}{E_2/a_2} = \frac{p_2}{v_2} \frac{v_3 - v_2}{p_3 - p_2}; \qquad \frac{E_1}{a_1} = \frac{p_2}{v_2}; \qquad \frac{E_2}{a_2} = \frac{p_3 - p_2}{v_3 - v_2};$$

$$\frac{a_1}{E_2} = \frac{a_1}{a_2} \frac{a_2}{E_2} = \frac{p_2}{v_2} \frac{(v_3 - v_2)^2}{(p_3 - p_2)^2}$$

and substituting the above equation leads to identify. With the numerical values used in this Example:

Input Energy:

$$\mathcal{E}_1 = p_3 v_3 = 4000 \times 62.9 = 251{,}600 \text{ lb. in.}$$

Energy at state p_2, v_2:

$$\mathcal{E}_2 = p_2 v_2 = 3500 \times 32.4 = 113{,}500 \text{ lb. in.}$$

Energy at state p_5, v_5:

$$\mathcal{E}_3 = (t_2 - 1) p_5 v_5 = 0.356 \times 1390 \times 12.9 = 6380 \text{ lb. in.}$$

Permanent strain of the $L_D = (t_1 - 1)a_1 = 23{,}000$ in. length is:

$$e = L_D (p_3 - p_2) \left(\frac{1}{E_2} - \frac{1}{E_1} \right) = 35.2 \text{ in.}$$

Deformation energy:

$$\mathcal{E}_4 = (t_1 - 1)a_1 \frac{p_3^2 - p_2^2}{2}\left(\frac{1}{E_2} - \frac{1}{E_1}\right) = 131{,}500 \text{ lb. in.}$$

which satisfies the equation of energy within computational error.

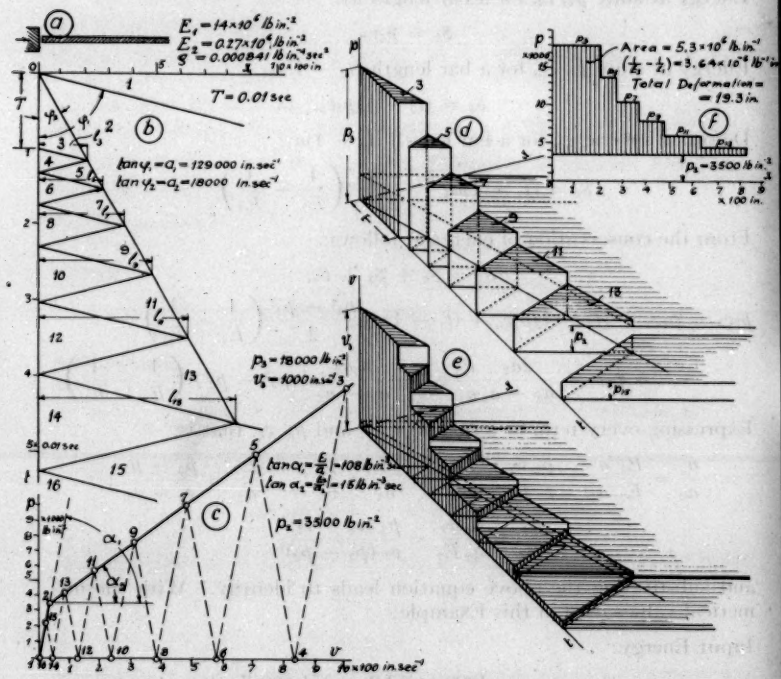

FIG. 18. Impact considerably above elastic limit, in compression, bar of infinite length.

(a) Schematic arrangement.
(b) Location diagram.
(c) Diagram of state.
(d) Stereogram of stress.
(e) Stereogram of velocity.
(f) Deformation diagram.

Problem 12. Impact Stress Considerably Above Elastic Limit, in Compression, of Infinite Bar (Fig. 18)

An impact at higher velocity, $v_3 = 1000$ in. sec.$^{-1}$, is analyzed in Fig. 18, making again the simplifying assumption, that the stiffness factor E_2 above the elastic limit is constant. The material is assumed

to be annealed copper, as in the previous example. The impact stress is 18,000 lb. in.$^{-2}$, at which the actual stiffness factor is 0.20×10^6 lb. in.$^{-2}$ (see Fig. 16); at the elastic limit, $p_2 = 3500$ lb. in.$^{-2}$, the stiffness factor is about 0.34×10^6 lb. in.$^{-2}$. Therefore the analysis will be performed with a mean value $E_2 = 0.27 \times 10^6$ lb. in.$^{-2}$, corresponding to values $a_2 = 18{,}000$ in. sec.$^{-1}$, and $E_2/a_2 = 15$ lb. in.$^{-3}$ sec.

The location diagram and the diagram of state are given in Fig. 18(b) and (c), from which the stereograms of stress, Fig. 18(d), and of velocity, Fig. 18(e), can be constructed. These give a very clear mental picture of the changes of pressure and velocity during and after the impact period. It is seen that after the termination of impact (at the end of the period when the stress p_3 is reduced to zero) repeated internal reflections take place at stresses of ever decreasing intensity (p_5, p_7, . . .) affecting an ever increasing length of the bar, and taking more and more time, until the stress decreases to a value p_{15} below the elastic limit. In the p-stereogram these changes appear as flat-topped peaks p_3, p_5, p_7 . . . arising out of a large plateau of p_2 value, and a foothill of p_{15}, above the t–x plane. Thus, while the impact itself lasts only $T = 0.01$ sec., the disturbance wave is of much longer duration, in this case 0.053 sec. After it passes, it leaves in its wake a portion of bar, 850 in. long, permanently strained. Two adjoining elastic waves remain in the bar: one of intensity p_2 and 0.04 sec. duration, and the adjoining one of intensity p_{15} of 0.013 sec. duration which are traveling along the bar with the velocity of propagation $a_1 = 129{,}000$ in. sec.$^{-1}$.

Interest attaches to the total amount of permanent deformation suffered by the portion of the bar which was subjected to stresses above the yield point. Referring to the t–x diagram Fig. 18(b) it is seen that the first length $l_3 = 200$ in. of the bar is subjected to stress p_3, then the first length $l_5 = 260$ in. to p_5 stress, then again the first length $l_7 = 370$ in. to stress p_7, and so on, until finally the first length $l_{13} = 850$ in., to stress p_{13}, beyond which distance only elastic, but not plastic deformation will take place. In calculating the total permanent deformation, it is assumed (with more or less experimental verification) that once the bar has been subjected to a stress p_i beyond the elastic limit, then the elastic limit has been raised thereby to p_i, and only stresses above will produce a further yield of the bar. Thus, with the notations of Fig. 18 the total permanent deformation will be:

$$D = \left(\frac{1}{E_2} - \frac{1}{E_1}\right)[(p_3 - p_2)l_3 + (p_5 - p_2)(l_5 - l_3) + (p_7 - p_2)(l_7 - l_5) + (p_9 - p_2)(l_9 - l_7) + (p_{11} - p_2)(l_{11} - l_9) + (p_{13} - p_2)(l_{13} - l_{11})],$$

which is equal to:

$$D = \left(\frac{1}{E_2} - \frac{1}{E_1}\right)[(p_3 - p_5)l_3 + (p_5 - p_7)l_5 + (p_7 - p_9)l_7 + (p_9 - l_{11})l_9 + (p_{11} - p_{13})l_{11} + (p_{13} - p_2)l_{13}.$$

The graphical significance of the expression within the square parenthesis is the boundary silhouette of the p-stereogram, projected against the p–x plane, integrated above the p_2 line, as shown in Fig. 18(f). The area multiplied by the $(1/E_2 - 1/E_1)$ factor gives the total permanent deformation. In the present example:

$$\text{Area} \times \left(\frac{1}{E_2} - \frac{1}{E_1}\right) = 5.3 \times 10^6 \times 3.64 \times 10^{-6} = 19.3 \text{ in.}$$

Problem 13. Impact Above Elastic Limit, in Compression, of Finite Bar, with Other End Free (Fig. 19)

The numerical data, the location diagram, and the diagram of state are given in Fig. 19(a), (b), and (c). The assumed length of the bar is 64.5 in.; it is subjected at its one end to a sustained impact velocity of 150 in. sec.$^{-1}$. The wave 2 corresponding to the elastic limit of 3500 lb. in.$^{-2}$, and a velocity of $v_2 = 32.3$ in. sec.$^{-1}$, arrives at the free end at the $t = 0.0005$ sec. instant; the stress is relieved there, and the wave 4 ($v_4 = 64.6$ sec.$^{-1}$, $p_4 = 0$) returns towards the impact end. The wave 3 corresponding to the impact velocity ($v_3 = 150$ in. sec.$^{-1}$, $p_3 = 5275$ lb. in.$^{-2}$) in the meantime proceeds towards the free end with the velocity a_2 of propagation, and meets the returning wave 4 at the 0.000875 sec. instant whereby the plastic wave 6, and elastic wave 5, are originated, traveling towards the two ends of the bar. The further progress of the stress-velocity phenomenon can be followed in the v–p diagram, Fig. 19(c), and the domains for which successive states 7, 8, 9 . . . are valid can be determined in the t–x diagram. In the v–p diagram changes of state below the elastic limit of 3500 lb. in.$^{-2}$, and also changes of state at decreasing stress take place along tan $\alpha_1 = E_1/a_1$ directrices; changes of state above the elastic limit and at increasing stress take place along tan $\alpha_2 = E_2/a_2$ directrices. It can be observed that whenever in the t–x diagram two adjacent domains are *separated* by a tan φ_1, or a tan φ_2 line, then in the v–p diagram the corresponding states are *connected* by a tan α_1, or a tan α_2 directrix, respectively.

The stereograms of stress and of velocity may be constructed from the data of Fig. 19(b) and (c) without difficulty.

Particular interest attaches to the history of velocity at the two ends of the bar. At the $T = 0.00235$ sec. instant the impact end of the bar attains a velocity higher than the impact velocity, $v_{16} = 162$ in. sec.$^{-1}$, and the bar separates from the hammer, the impact ends. The free end of the bar has gradually attained and surpassed the impact velocity, in steps of v_4, v_8, v_{13}, v_{17}, etc. The mean velocity of the bar is of the order of 170 in. sec.$^{-1}$, and there remains in the bar a residual elastic energy which is continually interchanged from stress energy to velocity energy and *vice versa*.

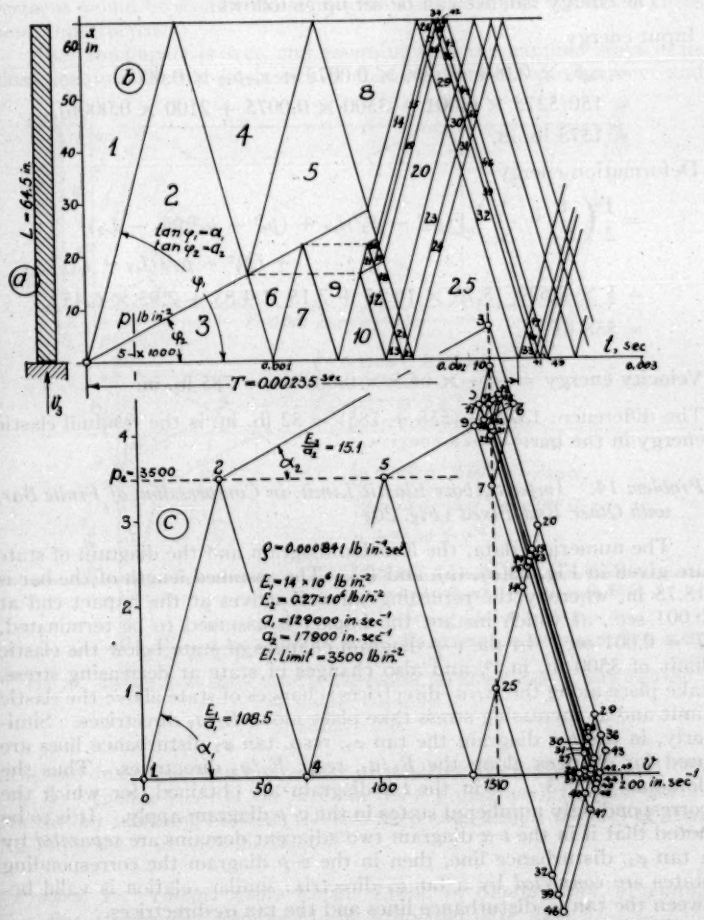

FIG. 19. Impact above elastic limit, in compression, bar of finite length, with free end.

(a) Schematic arrangement.
(b) Location diagram.
(c) Diagram of state.

The energy balance can be set up as follows:

Input energy

$$= v_3 p_3 \times 0.001 + v_7 p_7 \times 0.0075 + v_{12} p_{12} \times 0.0006,$$
$$= 150(5275 \times 0.001 + 3500 \times 0.0075 + 2100 \times 0.0006),$$
$$= 1375 \text{ lb. in.}$$

Deformation energy

$$= \frac{1}{2}\left(\frac{1}{E_2} - \frac{1}{E_1}\right)[(p_3^2 - p_2^2)L_3 + (p_6^2 - p_2^2)(L_6 - L_3) + (p_9^2 - p_2^2)(L_9 - L_6)],$$
$$= \tfrac{1}{2} \times 3.629[15.75 \times 16.15 + 7.15 \times 4.85 + 2.95 \times 6.45],$$
$$= 558 \text{ lb. in.}$$

Velocity energy $= \frac{170^2}{2} \times 64.5 \times 0.000841 = 785$ lb. in.

The difference: $1375 - (558 + 785) = 32$ lb. in. is the residual elastic energy in the bar.

Problem 14. Impact Above Elastic Limit, in Compression, of Finite Bar, with Other End Fixed (Fig. 20)

The numerical data, the location diagram and the diagram of state are given in Fig. 20(*a*), (*b*), and (*c*). The assumed length of the bar is 15.75 in. whereby the returning wave 5 arrives at the impact end at 0.001 sec., at which instant the impact is assumed to be terminated, $T = 0.001$ sec. In the v–p diagram changes of state below the elastic limit of 3500 lb. in.$^{-2}$, and also changes of state at decreasing stress, take place along the E_1/a_1 directrices; changes of state above the elastic limit and at increasing stress take place along E_2/a_2 directrices. Similarly, in the t–x diagram the tan φ_1, resp. tan φ_2 disturbance lines are used for changes along the E_1/a_1, resp. E_2/a_2 directrices. Thus the domains 1, 2, 3 . . . in the t–x diagram are obtained, for which the correspondingly numbered states in the v–p diagram apply. It is to be noted that if in the t–x diagram two adjacent domains are *separated* by a tan φ_1, disturbance line, then in the v–p diagram the corresponding states are *connected* by a tan α_1 directrix; similar relation is valid between the tan φ_2 disturbance lines and the tan α_2 directrices.

The final result is that the l_7 portion of the bar is stressed and correspondingly deformed by $p_7 = 6261$ lb. in.$^{-2}$, and the l_5 portion of the bar is stressed and deformed by $p_5 = 5123$ lb. in.$^{-2}$. The total deformation energy is 488 in. lb., while the input energy is 499 in. lb. The difference remains in the bar in the form of elastic energy, which is continuously interchanged from potential to kinetic energy and *vice*

versa, as would be seen in the stereograms of stress and velocity if these were constructed.

After the impact is over, and assuming that the hammer stays in its final position, the bar is elastically clamped between the hammer and

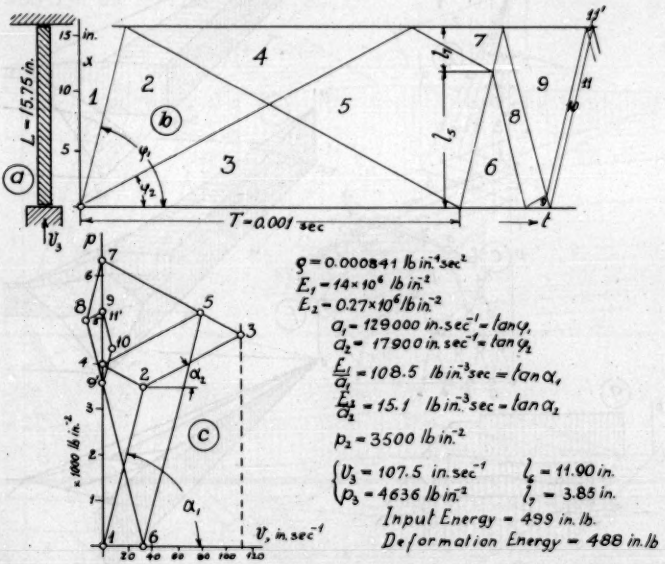

FIG. 20. Impact above elastic limit, in compression, bar of finite length, with fixed end.

(*a*) Schematic arrangement.
(*b*) Location diagram.
(*c*) Diagram of state.

the end mass, exerting a pressure alternating between 3500 and 6500 lb. in.$^{-2}$ (points 9, 9′, 11, 11′, etc., in the v–p diagram), the mid-portion of the bar vibrating between the two fixed ends with a velocity of about ± 14 in. sec.$^{-1}$ in both directions.

Problem 15. Impact Above Elastic Limit, in Compression, of Infinite Bar, Gradually Changing Elastic Properties (Fig. 21)

The velocity of propagation $a_1 = \tan \varphi_1$, and also the wave factor $E_1/a_1 = \tan \alpha_1$ are constant within the range of 0 stress up to the elastic limit. Henceforth they change abruptly to a new $\tan \varphi_2$ and $\tan \alpha_2$ value, and from the elastic limit onward they gradually change to $\tan \varphi_a$, $\tan \varphi_b$, $\tan \varphi_3$, and $\tan \alpha_a$, $\tan \alpha_b$, $\tan \alpha_3$. Assuming an impact at v_3

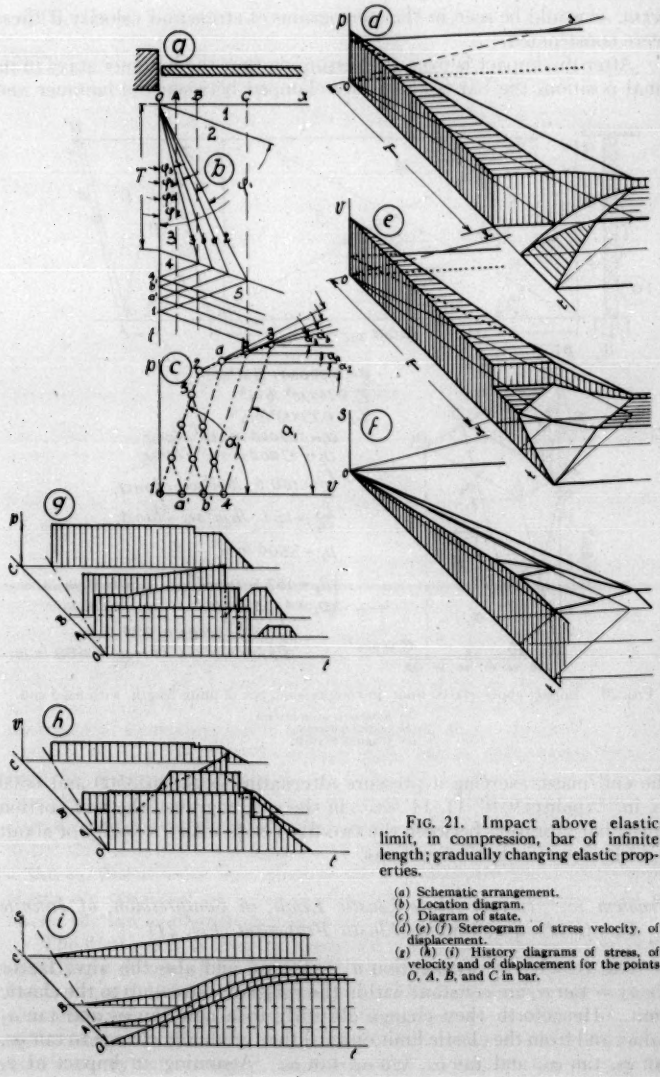

FIG. 21. Impact above elastic limit, in compression, bar of infinite length; gradually changing elastic properties.

(a) Schematic arrangement.
(b) Location diagram.
(c) Diagram of state.
(d) (e) (f) Stereogram of stress velocity, of displacement.
(g) (h) (i) History diagrams of stress, of velocity and of displacement for the points O, A, B, and C in bar.

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velocity lasting T time the t–x and v–p diagrams are given in Fig. 21(b) and (c). Constructing the stereograms Fig. 21(d) and (e) it is seen that the end portion of the impact is represented by gradually sloping surfaces and with plateaus of constant states corresponding to points 2, 3, 4, and 5 in the v–p diagram.

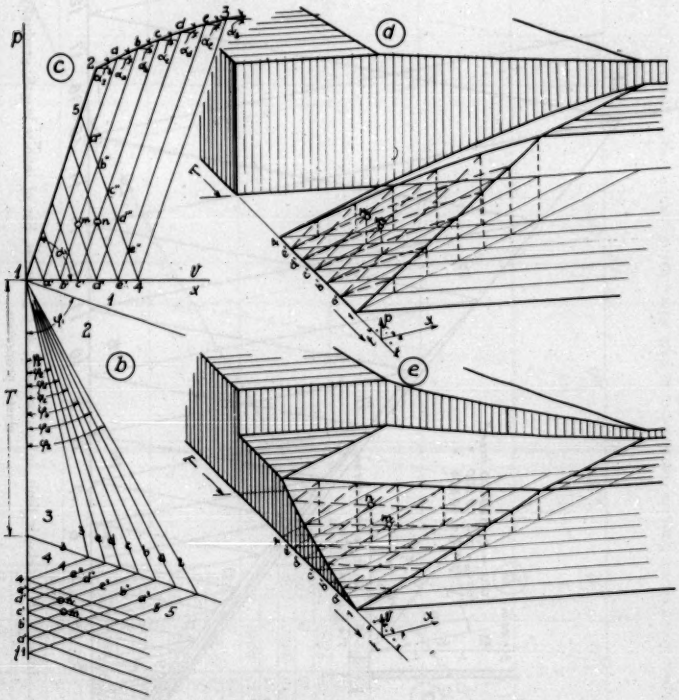


FIG. 22. End of impact period for case of Fig. 21.

(b) Location of diagram.
(c) Diagram of state.
(d) Stereogram of stress.
(e) Stereogram of velocity.

In order to show the phenomenon with greater clarity, Fig. 21(g) and (h) show the history diagrams of stress and velocity for 4 cross sections: 0, A, B, C; from Fig. 21(h), by integration the history of displacement, Fig. 21(i) can be derived, which in their entirety form the stereogram of displacement, Fig. 21(f).

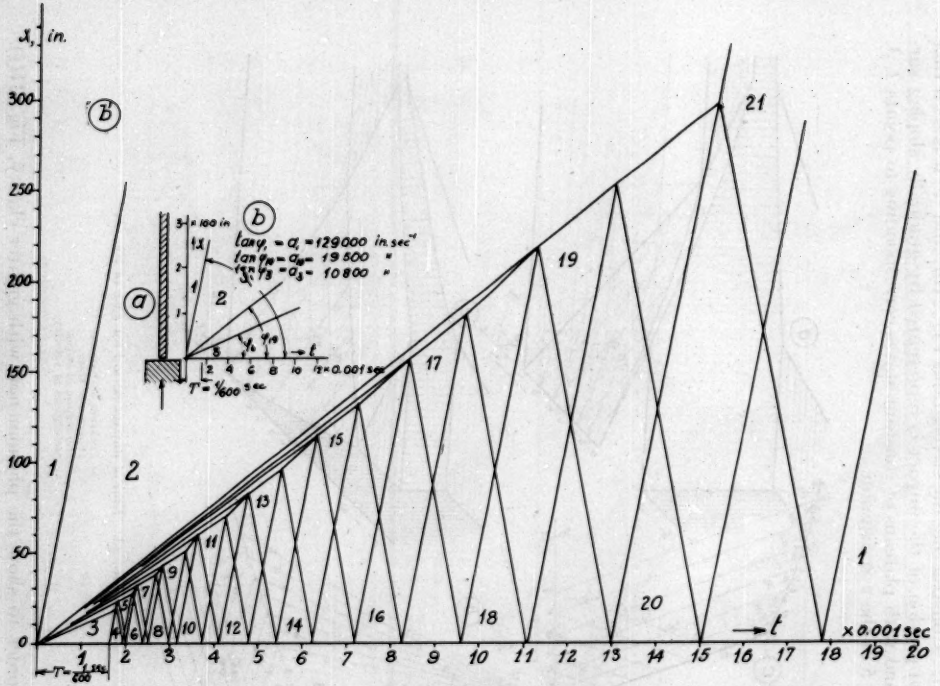
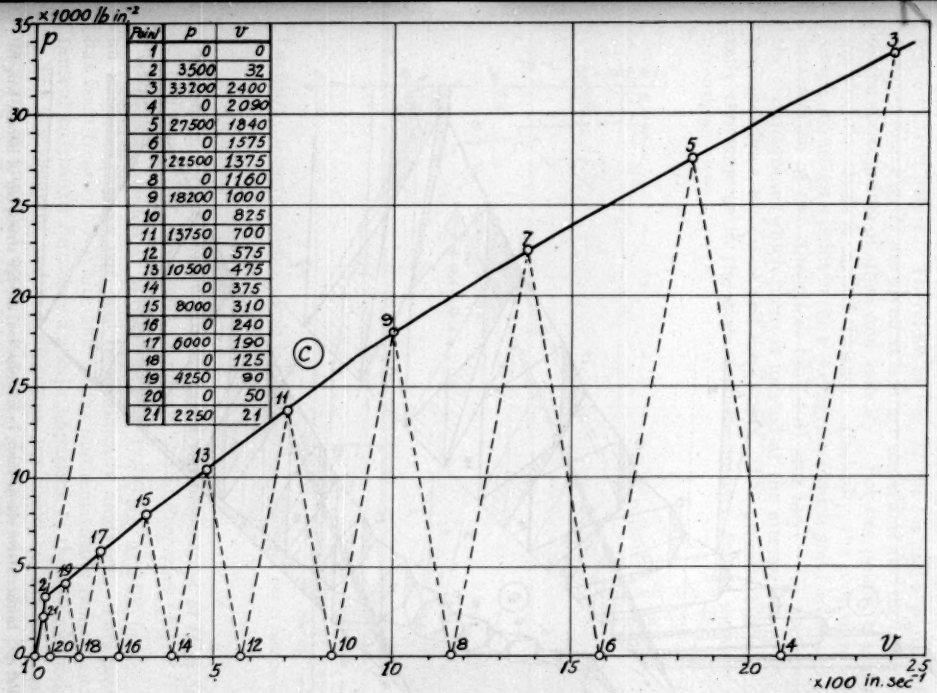


FIG. 23(*a*, *b*, *b'*). Impact above elastic limit, in compression, at high stress, bar of infinite length; gradually changing elastic properties.

(*a*) Schematic arrangement.
(*b*) Location diagram.
(*b'*) Location diagram at enlarged scale.



Point	p	v
1	0	0
2	3500	32
3	33200	2400
4	0	2090
5	27500	1840
6	0	1575
7	22500	1375
8	0	1160
9	18200	1000
10	0	825
11	13750	700
12	0	575
13	10500	475
14	0	375
15	8000	310
16	0	240
17	6000	190
18	0	125
19	4250	90
20	0	50
21	2250	21

FIG. 23(*c*). Impact above elastic limit, in compression, at high stress, bar of infinite length; gradually changing elastic properties.

(*c*) Diagram of state.

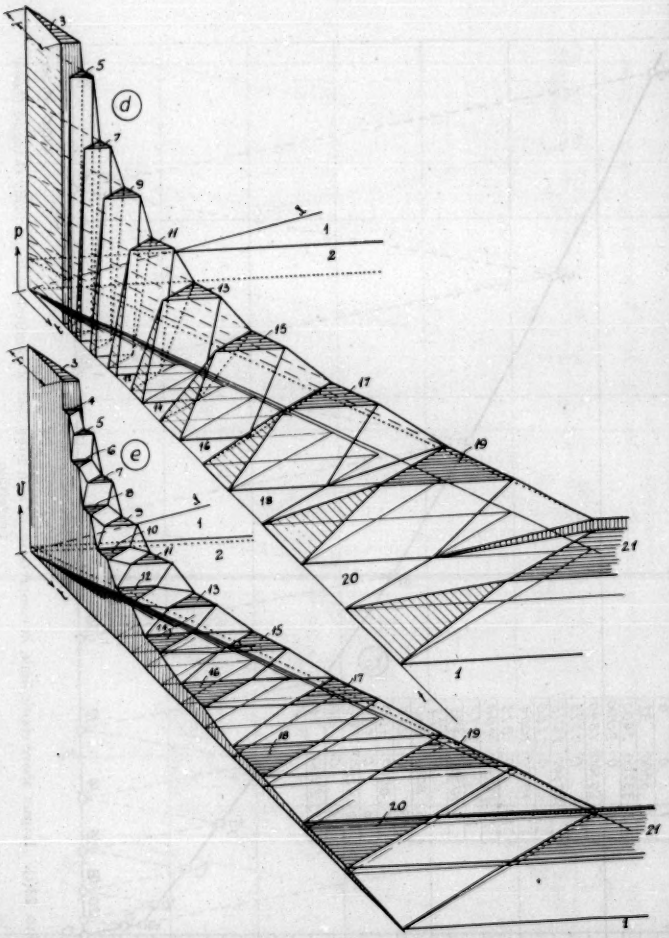


FIG. 23(*d*, *e*). Impact above elastic limit, in compression, at high stress, bar of infinite length; gradually changing elastic properties.

(*d*) Stereogram of stress.
(*e*) Stereogram of velocity.

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The construction of the sloping portions of the stereogram is of interest, because this condition did not arise in the examples of elastic impact given before. Therefore in Fig. 22 the t–x and v–p diagrams of the previous Fig. 21 are given at a larger scale, and also the end portion of the stereograms of stress and velocity. For two points, m and n the graphical analysis is carried through. Basically, the procedure is quite simple, to assign a point in the v–p diagram (which point is located at the intersection of two directrices tan $(+\alpha)$ and tan $(-\alpha)$), to a point in the t–x diagram (which point is located at the intersection of two disturbance lines, tan $(+\varphi)$ and tan $(-\varphi)$). The procedure is fundamentally the same as in the case of elastic impact, but it requires more attention.

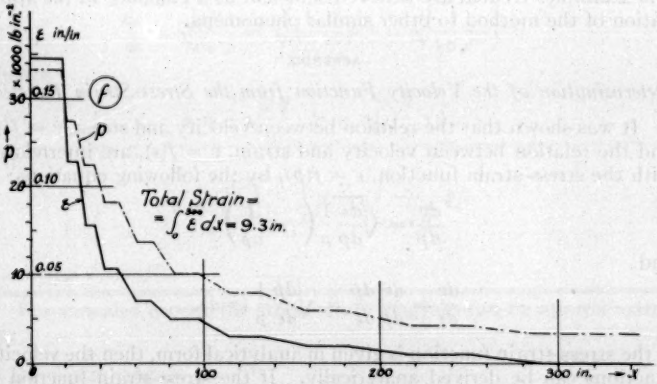


FIG. 23(*f*). Impact above elastic limit, in compression, at high stress, bar of infinite length; gradually changing elastic properties.

(*f*) Deformation diagram.

Problem 16. Impact Above Elastic Limit, in Compression, at High Stress, of Infinite Bar, Gradually Changing Elastic Properties (Fig. 23)

The compression at impact for $T = 1/600$ sec. at 2400 in. sec.$^{-1}$, of an annealed copper bar, will be graphically analyzed. This problem has been treated by White and Griffis mathematically before, and the present treatment furnishes a good comparison of the two methods.

The t–x diagram and v–p diagrams are based on the stress strain diagram of annealed copper, Fig. 16. The procedure can be readily followed on the basis of the former examples. The stereograms of stress and velocity are given in Fig. 23(*d*) and (*e*). It is of interest to determine the total permanent deformation undergone by the bar. In a manner similar to that of a previous example (Fig. 18(*f*)) also in this

case the silhouette of the stress stereogram is taken on the p–x coordinate plane, Fig. 23(f). From this the corresponding strain diagram ϵ–x is determined on the basis of the $\epsilon = f(p)$ curve. The area of the ϵ–x line above the elastic limit gives the total elongation $\int_0^{300} \epsilon dx = 9.3$ in. (Fig. 23(f)).

The data obtained by graphical analysis agree with the mathematically determined results of the previous authors within the limits of computational and constructional error.

CONCLUSION

The graphical method of analysis of impact in the elastic and plastic range has been explained, and numerous applications have been given. The examples treated are believed sufficient as a guidance in the application of the method to other similar phenomena.

APPENDIX

Determination of the Velocity Function from the Stress-Strain Function

It was shown that the relation between velocity and stress, $v = f(p)$ and the relation between velocity and strain, $v = f(\epsilon)$, are interrelated with the stress-strain function, $\epsilon = f(p)$, by the following equations:

$$\frac{dv}{dp} = \sqrt{\frac{d\epsilon}{dp}\frac{1}{\rho}} \left(= \frac{1}{a\rho} \right),$$

and

$$\frac{dv}{d\epsilon} = \frac{dv}{dp}\frac{dp}{d\epsilon} = \sqrt{\frac{dp}{d\epsilon}\frac{1}{\rho}} \; (=a).$$

If the stress-strain function is given in analytical form, then the velocity functions can be derived analytically. If the stress-strain function is given graphically by a curve then the velocity functions can be determined by means of graphical construction. Examples will be given of both procedures.

Analytical Method

Assume that the stress-strain function is represented in the range of $0 < p < p_1$ and $0 < \epsilon < \epsilon_1$ by a straight line:

$$\epsilon = Ap \quad \text{(elastic range)},$$

and beyond that, that is, for $p_1 < p$, $\epsilon_1 < \epsilon$ values, by a quadratic parabola:

$$\epsilon = Bp^2 \quad \text{(plastic range)},$$

which two lines join at the p_1, ϵ_1 point for which:

$$Ap_1 = Bp_1^2; \qquad \text{i.e., } p_1 = \frac{A}{B}; \qquad \epsilon_1 = \frac{A^2}{B} \quad \text{(elastic limit)}.$$

The velocity functions can be expressed in the elastic range:

$$\frac{dv}{dp} = \sqrt{\frac{d\epsilon}{dp}\frac{1}{\rho}} = \sqrt{\frac{A}{\rho}} \qquad \text{and} \qquad \frac{dv}{d\epsilon} = \sqrt{\frac{1}{A\rho}};$$

$$v = \sqrt{\frac{A}{\rho}} \cdot p, \qquad \text{and} \qquad v = \sqrt{\frac{1}{A\rho}} \cdot \epsilon,$$

and in the plastic range:

$$\frac{d\epsilon}{dp} = 2Bp, \qquad \frac{dv}{dp} = \sqrt{\frac{d\epsilon}{dp}\frac{1}{\rho}} = \sqrt{\frac{2B}{\rho}} \cdot p^{\frac{1}{2}},$$

and

$$\frac{dv}{d\epsilon} = \sqrt{\frac{dp}{d\epsilon}\frac{1}{\rho}} = \sqrt{\frac{1}{2B\rho}} \cdot p^{-\frac{1}{2}} = \sqrt[4]{\frac{1}{4B\rho^2}} \cdot \epsilon^{-\frac{1}{4}},$$

whence

$$v = \frac{2}{3}\sqrt{\frac{2B}{\rho}} \cdot p^{\frac{3}{2}} = \sqrt{\frac{8}{9}\frac{B}{\rho}}\sqrt{p^3},$$

and

$$v = \sqrt[4]{\frac{1}{4B\rho^2}} \cdot \frac{4}{3}\epsilon^{\frac{3}{4}} = \sqrt{\frac{8}{9\rho\sqrt{B}}}\sqrt[4]{\epsilon^3}.$$

Numerical Example

For annealed copper the stress-strain diagram can be approximated by:

in the elastic range

$$\epsilon = Ap = \frac{1}{E_0}p, \qquad A = \frac{1}{14 \times 10^6} = 0.0715 \times 10^{-6},$$

and in the plastic range

$$\epsilon = Bp^2, \qquad B = 1.5 \times 10^{-10}.$$

(This gives for the elastic limit: $p_1 = A/B = 475$ lb. in.$^{-2}$ instead of the actual 3500 lb. in.$^{-2}$. For a closer approximation a better fitted curve could be obtained by a parabola of higher order. But for the purpose of illustration the present assumption of a quadratic parabola appears to be adequate.)

The velocity functions will be for the elastic range:

$$v = \sqrt{\frac{0.0715 \times 10^{-6}}{0.000841}} \cdot p = 0.92 \times 10^{-2}p$$

and

$$v = \sqrt{\frac{1}{0.0715 \times 10^{-6} \times 0.000841}} = 129{,}000\epsilon,$$

and for the plastic range:

$$v = \sqrt{\frac{9}{8} \cdot \frac{1.5 \times 10^{-10}}{0.000841}} \sqrt{p^3} = 4 \times 10^{-4} \sqrt{p^3}$$

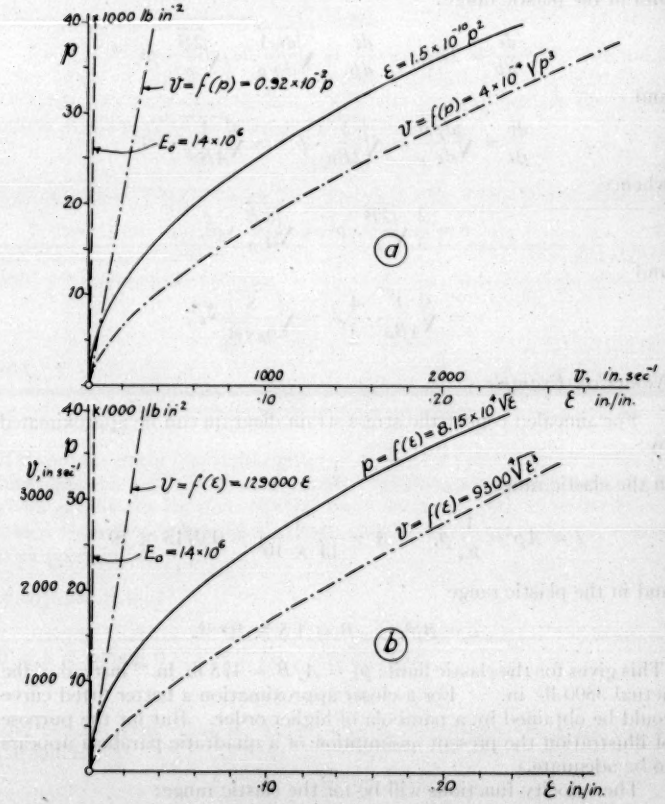
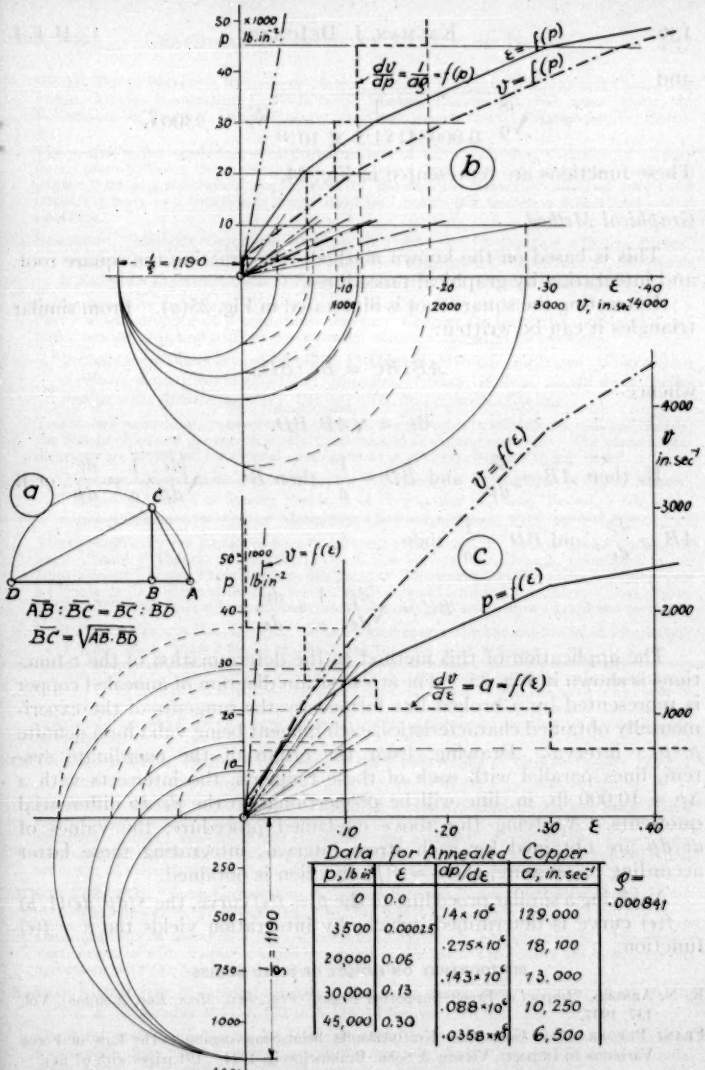


FIG. 24. Determination of the velocity function from the stress-strain function. (Functions given by formulas.)

(a) $v = f(p)$ derived from $\epsilon = f(p)$.
(b) $v = f(\epsilon)$ derived from $p = f(\epsilon)$.



Data for Annealed Copper

p, lb in.$^{-2}$	ε	$dp/d\varepsilon$	a, in. sec.$^{-1}$
0	0.0	14×10^6	129,000
3500	0.00025	$.275 \times 10^6$	18,100
20,000	0.06	$.143 \times 10^6$	13,000
30,000	0.13	$.088 \times 10^6$	10,250
45,000	0.30	$.0358 \times 10^6$	6,500

$g = .000841$

FIG. 25. Determination of the velocity function from the stress-strain function. (Functions given graphically.)

(a) Method of extracting square root.
(b) Relations as functions of stress.
(c) Relations as functions of strain.

and

$$v = \sqrt{\frac{8}{9} \cdot \frac{1}{0.000841\sqrt{1.5 \times 10^{-10}}}} \sqrt[4]{\epsilon^3} = 9300\sqrt[4]{\epsilon^3}.$$

These functions are represented in Fig. 24.

Graphical Method

This is based on the known methods of extracting the square root, and integration by graphical procedures.

Extracting the square root is illustrated in Fig. 25(*a*). From similar triangles it can be written:

$$\overline{AB}:\overline{BC} = \overline{BC}:\overline{BD},$$

whence

$$\overline{BC} = \sqrt{\overline{AB} \cdot \overline{BD}}.$$

If, then $\overline{AB} = \frac{d\epsilon}{dp}$, and $\overline{BD} = \frac{1}{\rho}$, then $\overline{BC} = \sqrt{\frac{d\epsilon}{dp} \cdot \frac{1}{\rho}} = \frac{dv}{dp}$, or if $\overline{AB} = \frac{dp}{d\epsilon}$, and $\overline{BD} = \frac{1}{\rho}$, then

$$\overline{BC} = \sqrt{\frac{dp}{d\epsilon} \cdot \frac{1}{\rho}} = \frac{dv}{d\epsilon}.$$

The application of this method to the determination of the v-functions is shown in Fig. 25. The stress-strain diagram of annealed copper is represented by a broken line formed by the tangents of the experimentally obtained characteristics, each tangent being valid for a definite $p_i - p_{i-1}$ interval. Drawing, from the origin of the coordinate system, lines parallel with each of these tangents, the intersects with a $\Delta p = 10{,}000$ lb. in. line will be proportional to the $d\epsilon/dp$ differential quotients. Applying the above explained procedure, the values of dv/dp are obtained for each stress interval; integrating these latter according to pressure, the $v = f(p)$ function is obtained.

Applying a similar procedure to the $p = f(\epsilon)$ curve, the $\sqrt{(dp/d\epsilon)(1/\rho)} = f(\epsilon)$ curve is determined, which, by integration yields the $v = f(\epsilon)$ function.

BIBLIOGRAPHY ON IMPACT OF SOLID BODIES

R. N. ARNOLD, "Impact of Freely Supported Beam," *Proc. Inst. Mech. Eng.* (London), Vol. 137, 1937.

FRANZ BERGER, "Das Gesetz des Kraftverlaufes beim Stossvorgang" (The Law of Force Variation in Impact), Vieweg & Sohn, Braunschweig, 1924. 191 pages with 67 figs.

An extensive historical survey of impact theories and experiments up to 1924, based partly on the work of Todhunter and Pearson: "History of the Theory of Elasticity. Vol. I and II," Cambridge 1887–1893. Discusses the investigations of Galilei (1638), Marcus Marci, John Wallis, Christopher Wren, Christian Huygens, Mariotte, Newton, Robins, Jacopo

Riccati, Daniel Bernoulli, Boussinesq, Navier, Poisson, Hodgkinson, Lamé and Clapeyron, Morin, Young, Homersham Cox, de Saint Vénant, Hamburger, Neumann, Hertz, L. Boltzmann, W. Voigt, V. Hausmanninger, A. Ritter, Dunn, Hatt, C. Ramsauer, W. Hoeniger.

The author's own work treats mathematically and experimentally: variation of impact force, point-by-point determination of force-travel and force-time diagram, maximum impact force as a function of impact velocity, deformation, travel of center of gravity of impacting body as a function of time, based on Hooke's law and on a generalized law of elasticity.

L. BERGERON, "Méthode Graphique Générale de Calcul des Propagation d'Ondes Planes" (General Graphical Method of Calculating the Propagation of Plane Waves), *Bulletin de la Société des Ingénieurs Civils de France*, Paris, July 1937, 93 pp., with 43 figures.

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——, "Propagation d'Ondes le long des Lignes Électriques; Méthode Graphique" (Propagation of Waves along Electric Conduits; Graphical Method), *Bulletin No. 82 de la Société Française des Électriciens*, Paris, October 1937, 26 pp., with 21 figures.

Treats the longitudinal, transverse and torsional disturbances in solid elastic rods and chords; the flow in pipes and in open channels; disturbances in electric conduits. The plane surge-diagrams are presented for several combinations of electric elements in full detail.

——, "Méthode Graphique de Résolutions des Problèmes de Propagation d'Ondes Planes" (Graphical Method of Solving Problems of Propagation of Plane Waves), Fifth International Congress for Applied Mechanics, Cambridge, Mass., 1938, pp. 694–699.

Treats graphically the impact of bars of different cross sections. Refers to the work of de Saint Vénant ("Théorie de l'Élasticité des Corps Solides" by Clebsch, translated by de Saint Vénant, Dunod, Paris, 1883, p. 480), and of Boussinesq ("Application des Potentiels à l'Étude de l'Équilibre et du Mouvement des Solides Élastiques" Gauthiers-Villars, Paris, 1885, p. 507) and finds agreement between their analytical and his own graphical methods.

H. F. BOHNENBLUST AND POL. DUWEZ, "Some Properties of a Mechanical Model of Plasticity," *J. App. Mech.*, 1948. Paper No. 48-APM-10, 4 pp. with 8 figures.

Various mechanical models explaining the plastic deformation of metals have been proposed. In some cases an analytical expression for the stress-strain curve and the hysteresis curve of a metal in the plastic range can be deduced from the model. An analysis of the model is presented from which the change of potential energy of the metal due to work hardening can be computed.

D. S. CLARK AND P. E. DUWEZ, "Discussion of the Forces Acting in Tension Impact Tests of Materials," *J. App. Mech.*, 1948. Paper No. 48-APM-15, 5 pp. with 10 figures.

Method of measuring forces acting on a specimen during a tension-impact test made with a rotary impact machine, used in conjunction with a dynamometer attached to the fixed end of specimen. Impact velocity of 200 ft. per sec. was attained. Computation of force-time relation based on the theory of propagation of elastic and plastic strain. Graphical representation of velocity versus stress, and distance versus time. Bibliography of 11 titles.

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Describes tests on metal rods of various dimensions, struck with short bars. The strains were measured with resistance strips cemented to the bar. The results are in substantial agreement with the conclusions of the theory.

KALMAN J. DEJUHASZ, "Graphical Analysis of Impact of Elastic Bars," *J. App. Mech.*, Vol. 9, No. 3. September 1942, A-122 to A-128, 14 figures.

Graphical analysis applied to longitudinal central impact of elastic bars; comparison of results with those arrived at mathematically; bars of different lengths and cross sectional areas; energy state before and after the impact. Bibliography of 9 titles.

In the discussion of this paper, *Jl. of Appl. Mech.*, June 1943, pp. A-111 to A-114, R. W. Angus points out the close analogy of water hammer phenomena to elastic impact, and directs attention to cases in which the impact force is great enough to cause plastic deformation.

C. O. DORRENWEND AND W. R. MEHAFFEY, "Dynamic Loading in Design," *Machine Design*, June 1943, pp. 99–104 with 8 figures and bibliography of 26 references.

Problems of design under rapid dynamic loads; comparison of dynamic and static yields; transient stress distribution; speed of shock wave; use of electric strain gage.

——, "Measurement of Dynamic Strain," *J. App. Mech.*, Vol. 10, No. 2 (June 1943), pp. A-85 to A-92 with 15 figures. Discussion in *J. App. Mech.*, Vol. 11, No. 1 (March, 1944), pp. A-57 to A-62, with 8 figures.

Instrumentation for the measurement of high and low frequency dynamic strains. Amplitude-modulation method is suitable for low frequencies from zero to about 15 per cent of the carrier frequency of 1025 cycles. Potentiometer type for high frequencies such as 100 cycles per second to 8000 cycles per second. The latter method is suitable for impact strains such as hammer blows, and forging equipment. Both units are used in conjunction with a cathode-ray oscillograph. Photographic records of impact strains in long elastic bars and of hammer blows on a steel tank are given.

L. H. DONNELL, "Longitudinal Wave Transmission and Impact," *Trans. A.S.M.E.*, Vol. 52, 1930. Paper APM 52-14, pp. 153–167 with 29 figures.

Treats mathematically and graphically a number of longitudinal wave problems, such as impact of finite mass against infinite mass; maximum and minimum compression in the bar during impact; longitudinal waves in railway trains; compression waves in helical springs and in liquid columns; waves in materials of non-linear elasticity.

W. M. DUDLEY, "Analysis of Longitudinal Motions in Trains of Several Cars," *J. App. Mech. (Trans. A.S.M.E.)*, December 1941, Vol. 8, No. 4, pp. A-145–151, with 10 figures.

With the aid of difference equations the motion of a train consisting of five cars is treated as five concentrated masses connected with springs. Velocity of waves of force in a train. A motion curve is given for the train when constant force is applied in succession to the cars.

P. E. DUWEZ AND D. S. CLARK, "An Experimental Study of the Propagation of Plastic Deformation Under Conditions of Longitudinal Impact," *Proc. Am. Soc. Testing Mats.*, Vol. 47 (1947), pp. 502–532 with 23 figures, 10 references. Discussion by L. H. Donnell, LeVan Griffis, and Merit P. White.

The theory of plastic strain propagation is reviewed with reference to longitudinal impact. Special testing machine for securing data for verification of theory. Tests in tension of long wires and on specimens with gage length of 8 inches; some results on compression tests. Effects of release of loading and reflection of plastic strain waves. Concept of critical velocity. The results indicate satisfactory agreement between theory and experiment.

R. FANNING AND W. V. BASSETT, "Measurement of Impact Strains by Carbon-Strip Extensometer," *J. App. Mech.*, Vol. 7, No. 1, pp. A-24 to A-28 with 7 figures. Discussion in Vol. 7, No. 3, Sept. 1940, pp. A-125 to A-127.

The stress-time curve in a mechanical element subjected to blow is experimentally determined. The apparatus consists of a resistance strain gage in connection with a recording oscillograph, capable of measuring strain variations occurring within a few microseconds.

R. O. FEHR, E. R. PARKER, AND D. J. DEMICHAEL, "Measurement of Dynamic Stress and Strain in Tensile Test Specimens," *Trans. A.S.M.E., J. App. Mech.*, Vol. 11, No. 2, June 1944, pp. A-65 to A-71, 18 figures.

The tensile strength, yield strength and breakage energy of test specimens were measured while the specimens were broken by a force applied at a high rate of speed in a high-velocity impact-testing machine. The dynamic values were found to be higher than the static values up to the maximum impact velocities of the tests (100 ft./sec.). Description of technique, of analysis, and of test results. Brief discussion of stress waves.

KURT FINK, "Die experimentelle Bestimmung des Fliessbeginns von Flusstaehlen bei schlagartiger Beanspruchung" (Experimental Determination of the Yield Point of Mild Steel under Impact Loading), *Archiv fuer das Eisenhuettenwesen* (Duesseldorf, Germany), Vol. 19 (1948), pp. 153–160, 13 figs.

Determination of the stress conditions under impact in compression and tension. Analysis of the impact process with the aid of the theory of propagation of elastic waves in solids. Considerable increase of the upper yield limit of rapidly stressed mild steel. Proposal for a systematic test program for investigating the dynamic behavior of materials.

LUDWIG FOEPPL, "Der Stoss" (The Impact), *Handbuch der Experimentalphysik*. Vol. II. Technische Mechanik. Chapter VI, pp. 151–170 with 2 figures. Publ. Akad. Verlagsgesellschaft, Leipzig, 1929.

A short summary of the theory of impact, and abstract of work of previous investigators, namely, H. Hertz, Franz Berger, Hamburger, C. Ramsauer, L. Boltzmann, W. Voigt, V. Hausmanninger.

H. GEIGER AND K. SCHEEL, "Handbuch der Physik," Julius Springer, Berlin, 1928, Vol. VI, Chapter 7. Poeschl, Th., "Der Stoss fester Koerper" (Impact of Solid Bodies), pp. 501–565, with 31 figures.

Gives an extensive summary of the theoretical and experimental treatment of impact problems, and synopses of the work of previous investigators. Impact of masspoints and rigid bodies; elastic theory of Neumann, de Saint Vénant, Flamant, Poeschl, and Hertz; fall of a body on a beam; experiments of Schneebeli, Pouillet, Boltzmann, Ramsauer, Voigt, and Berger.

E. T. HABIB, "A Method of Making High-Speed Compression Tests on Small Copper Cylinders," *J. App. Mech.*, 48-APM-9 (1948). 8 pp. with 14 figures.

Small copper cylinders compressed at high speeds are used to measure the pressure from underwater explosion. Apparatus is described for the dynamic calibration of these cylinders; results compared with results of other investigators. Propulsive system is a compressed-air operated piston thrown against the copper cylinder, which is supported against an anvil of large mass; velocity of piston can be varied by varying the air pressure. Energy absorbed by copper cylinder is measured by determining the velocity of the piston just before and after impact. Energy absorption depends on mass of piston used. Bibilography of 9 titles.

BERTRAM HOPKINSON, "The Effect of Momentary Stresses in Metals," *Proc. Royal Soc.*, Vol. 74, No. 505, March 16, 1906.

——, "The Pressure of a Blow," Scientific Paper No. 26. Cambridge University Press, 1921, pp. 423–437 with 9 figures.

Qualitative discussion of impact on balls, bars, explosion of gun cotton on a plate, impact of shell on armour plate. Discussion of velocity of propagation, of time of impact, of pressure of impact.

B. F. LANGER AND E. H. LAMBERGER, "Calculation of Load and Stroke in Oil-Well Pump Rods," *J. App. Mech., Trans. A.S.M.E.*, Vol. 10, No. 1, March 1943, pp. A-1 to A-12, with 20 figures.

The sucker-rod pump as used in oil wells is treated as a problem in the longitudinal vibration of bars. Solutions are obtained for the forces and motions at both ends of the rod string, thus giving formulas for the calculations of rod load and plunger travel. The results of calculations are compared with test results.

Discussion in *Journal of Applied Mechanics*, Sept. 1943, Vol. 10, No. 3, pp. A-178–179, with 4 figures, by K. J. DeJuhasz and A. Yorgiadis shows application of graphical analysis to the stress and velocity variations in a long rod having three different cross sections.

E. H. LEE, "The Impact of a Mass Striking a Beam," *Ibid.*, December 1940, Vol. 7, No. 4, pp. A-129 to A-138, with 11 figures.

An approximate theoretical solution of the equation of horizontal impact of a mass on a beam, making the assumption that the duration of contact is small in comparison with the fundamental mode of vibration of the beam.

H. C. MANN, "High Velocity Tension Impact Tests," *Proc. Am. Soc. Testing Mats.*, Vol. 36, 1936, Part II.

R. C. MANSLEY, "The Transient State and the Analysis of Shock Excitation," *Engineering*, Vol. 156, No. 4058, October 22, 1943, pp. 321–322, and No. 4060, November 5, 1943, pp. 361–363, with 8 figures.

Recurrent transients, such as the shock loading of crank-connecting rod mechanism under the action of explosions are discussed. Analysis by Fourier series.

LOUIS A. PIPES, "Theory of Longitudinal Impact," *J. App. Phys.*, August 1942, pp. 503–511, with 13 figures.

By making use of the analogy existing between the differential equations describing the longitudinal displacements and velocities of a uniform rod, and the charge and current along a uniform electrical transmission line, the known results of electrical circuit theory are translated into mechanical terms and the method of operational calculus applied to the former. The problem considered is that of determining the subsequent behavior of a long uniform thin rod that is struck on one end by a massive body moving in the direction of the length of the rod. Various states of mobility of the other end of the rod are assumed.

——, "Analysis of Longitudinal Motions of Trains by Electric Analog," *Ibid.*, Vol. 13, No. 12, December 1942, pp. 780–786, with 3 figures.

The relative motion of a train of n uniform cars and a locomotive is considered. If slack and rolling resistance are neglected the system may be idealized to that on $n+1$ masses connected by springs. To generalize the analysis it is assumed that identical shock absorbers of the dashpot and viscous friction type are placed between the units. By considering the electrical analog of this dynamical system its natural frequencies are determined. It is found that if the shock absorbers have a certain critical strength no free oscillation between the cars is possible. Expressions are obtained for the velocities of several cars when the locomotive exerts an oscillatory tractive effort. By the use of operational calculus the response of the system when the tractive effort is impulsive is also determined.

WILLIAM PRAGER, "The Stress-Strain Laws of the Mathematical Theory of Plasticity—A Survey of Recent Progress," *J. App. Mech.*, Paper No. 48-APM-14 (1948), 8 pages, 0 figures, with bibliography of 50 titles.

Typical stress-strain laws of flow and deformation types are discussed with particular reference to the conditions of continuity and uniqueness which these laws must fulfil if they are to make sense physically. Alternative forms of some of these laws are presented, and conditions are discussed under which different laws yield identical results. Methods of integration are indicated and the use of variational principles is stressed.

C. RAMSAUER, "Experimentelle und theoretische Grundlagen des elastischen und mechanischen Stosses" (Experimental and Theoretical Foundation of the Elastic and Mechanical Impact), *Annalen der Physik.*, Vol. 30, 1900, pp. 417–494.

Discussion of the history of impact problems, listing the work of previous investigators. Experiments on bars of various lengths and cross sectional areas.

M. RANKINE, "On the Problem of Impact," *The Engineer*, Vol. 58, February 15, 1857, pp. 133.

J. E. SEARS, "On the Impact of Bars with Rounded Ends," *Trans. Cambridge Philosophical Society*, Vol. 21, 1909–1911.

K. H. SWAINGER, "Strain Energy in Greatly Deformed Elastic or Inelastic Anisotropic Engineering Metals," JOUR. FRANKLIN INSTITUTE, Vol. 245, No. 6, June 1948, pp. 501–516, with 7 figures and bibliography of 20 titles.

The equilibrating stresses on an orthogonal element in a strained body induce normal strains defined as relative displacement per unit length of deformed body. The work done by the forces on the faces of an orthogonal element of unit volume in the loaded body during a differential increase of deformation is found. Integration gives the total work done on the element from the initial unstrained state up to the current state of deformation.

D. L. THORNTON, "Mechanics Applied to Vibrations and Balancing," John Wiley & Sons, Inc., 1940, New York, pp. 204–296.

Chapter IV deals with the propagation of stress in elastic materials, including phenomena in pile driving, vibrations in light wire, water hammer, spherical waves, elastic properties of earth, earthquakes, impact, transmission of energy by pressure waves, fuel systems in internal combustion engines, velocity of sound in various solids.

S. TIMOSHENKO, "Theory of Elasticity," McGraw-Hill Book Co., New York, 1934.

Chapter 12, pp. 381–403, "The Propagation of Waves in Elastic Solid Mediums," gives a summary of impact problems and their mathematical treatment. A history of these problems, as treated by several investigators, namely, Young, Cauchy, Poisson, de Saint Vénant, Boussinesq, and others, is briefly reviewed.

THEODORE VON KÁRMÁN, H. F. BOHNENBLUST, AND D. H. HYERS, "The Propagation of Plastic Waves in Tension Specimens of Finite Length," National Defense Research Committee. Report No. A-103. O.S.R.D. 946, October 1942, 38 pages with 15 figures.

The fundamental differential equations of wave propagation in elastic-plastic materials are given and methods of integration of these equations are discussed. The physical process is represented geometrically in two planes, the Lagrangean plane and the velocity plane. Problems of impact in specimens of finite length showing reflection of plastic waves. A graphical method is explained and applied to the case of an impirical stress-strain relation. The Hugoniot relations are written in Lagrangean form. The distribution of the residual strain along the specimen can be determined.

THEODORE VON KÁRMÁN AND POL. DUWEZ, "The Propagation of Plastic Deformation in Solids," Paper presented at the Sixth International Congress for Applied Mechanics, Paris, 1946. (To be published in the Proc. of the Congress, not yet published.) 21 pp. with 13 figures, bibliography of 6 titles.

Longitudinal impact at end of bar extending to infinity; bar of finite length; experiments on the propagation of plastic strains in a long specimen subjected to tension impact; experimental technique; results of high velocity impact tests; relation between velocity of impact and amplitude of plastic wave front; shape of plastic wave and velocity of propagation of the plastic front; force-time relation at fixed end of specimen subjected to tension impact; practical applications.

MERIT P. WHITE, "The Force Produced by Impact of a Cylindrical Body," National Defense Research Committee. Report No. A-157. March 1943, 19 pp. with 9 figures.

Two kinds of behavior are possible in compression impact: (1) the material of moving specimen is brought to rest by the stress waves propagated from the impact zone; this occurs in low-velocity impact. (2) The material is not stopped but flows away from the impact zone parallel to the target plane; this occurs at impact velocities above the "critical velocity." For very large velocities the force approaches the force produced by a fluid stream of the same density, velocity and area. This analysis has a bearing on the development of very high velocity.

MERIT P. WHITE AND LEVAN GRIFFIS, "Wave Propagation in a Uniform Bar whose Stress-Strain Curve is Concave Upward," National Defense Research Committee. Report No. A-152, February 1943. 14 pp. with 6 figures.

The plastic wave analysis recently developed for materials whose engineering stress-strain curves are concave downward is extended to materials for which the stress-strain curves are partly or entirely concave upward, but always with a positive slope. In this case a steady wave form is possibly one having a very sudden rise. This is identical to the shock wave occurring in gases. Expressions are developed for relating stress and strain, particle velocity, and velocity of wave propagation.

——, "The Permanent Strain in a Uniform Bar Due to Longitudinal Impact," *J. App. Mech.*, Vol. 14, No. 4, December 1947, pp. A-337 to A-343, with 15 figures.

A method is presented for predicting the final strained state of a long uniform bar or wire of ductile material that is subjected to a longitudinal impact of finite duration during which the impact stress is constant and exceeds the yield strength. The final strains are greatest immediately adjacent to the impact point and are constant over a finite length of the specimen. Bibliography of 7 titles.

——, "The Propagation of Plasticity in Uni-Axial Compression," *Ibid.*, Paper No. 48-APM-17, 5 pp. with 5 figures.

Four different kinds of behavior are analyzed: in the concave downward range of the stress-strain curve; in the inflexion point vicinity; in the concave-upward range of stress-strain curve; at supersonic rate of compression. Static and dynamic stress-strain relation is also discussed. Bibliography of 8 titles.

C. R. WIKANDER, "Draft-Gear Action in Long Trains," *Trans. A.S.M.E.*, Vol. 57, August 1935, pp. 317–334, with 45 figures.

A study of coupler pressures, car speeds and accelerations in a long train, produced by external forces; based on the similarity to an elastic bar of the same length of the train, the same mass per unit length and the same yield when subjected to longitudinal compressive or tensile forces. Diagrams of pressure and speed are derived for the various periods through which the waves are passing. Formulas are derived for the maximum bar pressures and tensions, for the locations at which they occur and for the maximum accelerations and retardations of the particles. Formulas are applied to freight trains of known characteristics.

——, "Draft-Gear Action in Train Service," *Ibid.*, Vol. 66, No. 8, November 1944, pp. 691–696, with 7 figures.

In order to investigate the most desirable characteristics of a draft gear by mathematical analysis, a study has been made of the mechanics of an elastic bar, which is subjected to external forces that correspond to those acting in trains under various service conditions. Numerical examples are given showing the application to assumed test trains.

——, "Dynamics of an Elastic Bar," *J. App. Mech.*, Vol. 12, No. 2, June 1945, pp. A-101 to A-106, with 3 figures.

The dynamics of an elastic bar, solid and with free slack, forms a convenient basis for the study of train dynamics, owing to the similitude of the individual cars in the long train to the particles in an elastic bar. It is assumed that the stress and strain in the solid parts of the bar are proportional. Behavior of elastic bars corresponding to the starting, the braking and the change in grade of the track of a long train without or with free slack.

V.2
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A NOTE ON ANALYSIS OF BEAM-COLUMNS UNDER ARBITRARY LATERAL LOAD AND END RESTRAINT

BY

R. H. SCANLAN[1]

While reviewing some basic relationships and subtleties of Euler column theory, the author was led to consider a general and novel method of analysis applicable to beam columns. He is indebted to M. Yachter for early suggestions on the method, which is presented here. The method applies to long, constant-section beam columns having elastically restrained ends and arbitrary lateral loads.

The beam-column problem for elastic members has been successfully solved for many years by numerous engineering investigators using approximate or specialized means. The present discussion is essentially mathematical, with suggestions for computation appended. The intent herein is to present a general solution rather than another particular one.

I. THE ELASTICALLY RESTRAINED COLUMN OF CONSTANT STIFFNESS

Consider a long column of length l, with P-load as shown in Fig. 1, with elastic end restraint moments $m_1 = c_1\theta_1$ and $m_2 = c_2\theta_2$ proportional

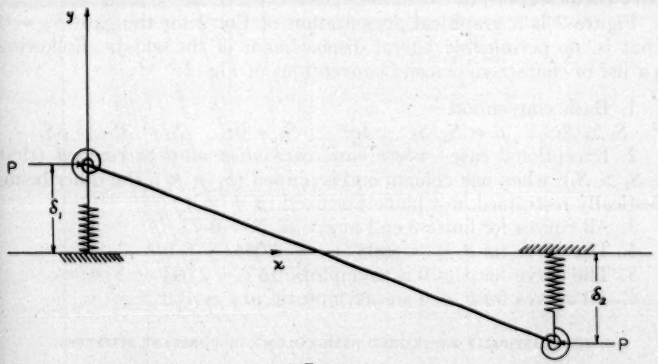

FIG. 1.

to the angular displacements θ_1 and θ_2 of the ends, and elastic and restraint forces $V = \delta_1 k_1 = \delta_2 k_2$ proportional to the lateral displace-

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ments δ_1 and δ_2 of the ends. If $\alpha^2 = P/EI$, the differential equation of the column is

$$y'' + \alpha^2 y = \alpha^2 \left(\delta_1 - \frac{Vx}{P} + m_1 \right), \tag{1}$$

with the end conditions

$$y(0) = \delta_1; \qquad y'(0) = \theta_1;$$
$$y(l) = \delta_2; \qquad y'(l) = \theta_2.$$

Let the usual critical load be given by

$$P_{CR} = \frac{c\pi^2 EI}{l^2};$$

then let $\gamma = \alpha l = \sqrt{c}\pi$, $S_1 = \dfrac{EI}{lc_1}$, $S_2 = \dfrac{EI}{lc_2}$, $S_L = \dfrac{EI}{l^3}\left(\dfrac{1}{k_1} + \dfrac{1}{k_2}\right)$. The critical column condition can then be shown to be equivalent to the transcendental equation

$$D(S_L, S_1, S_2, \gamma) = \gamma(\gamma^2 S_L - 1)[(\gamma^2 S_1 S_2 - 1)\sin\gamma - \gamma(S_1 + S_2)\cos\gamma] - [\gamma(S_1 + S_2)\sin\gamma + 2(1 - \cos\gamma)] = 0. \tag{2}$$

This result is well known (**2**, **3**, **5**),[2] except for the slight generalization due to inclusion of transverse linear springs. This equation furnishes a useful relation between column fixity coefficient c and end fixity coefficients c_1, c_2.

Figure 2 is a graphical presentation of Eq. 2 for the case $S_L = 0$ (that is, no permissible lateral displacement of the ends). Following is a list of characteristics and conventions of Fig. 2:

1. Basic convention—
   $S_1 \leqq S_2$; $\beta = S_1/S_2$ for $S_2 \neq 0$; $S_1 = \beta S_2 = \beta S$.
2. Exceptional case—*where basic convention must be reversed* (that is, $S_1 > S_2$): when one column end is pinned ($S_1 = \infty$), the other being elastically restrained, not pinned or fixed ($\beta = \infty$).
3. All curves for finite β end at $c = 4$, $S = 0$.
4. The curve for $\beta = \infty$ ends at $c = 2.044$, $S = 0$.
5. The curve for $\beta = 0$ is asymptotic to $c = 2.044$ at $S = \infty$.
6. All curves for $\beta \neq 0$ are asymptotic to $c = 1$ at $S = \infty$.

II. THE ELASTICALLY RESTRAINED BEAM-COLUMN OF CONSTANT STIFFNESS

Figure 3 represents a beam-column of constant EI and elastically restrained ends. The ends are assumed free to rotate but not to translate laterally. If m_1 and m_2 are the contributions to the end moments due to elastic restraints under *both* column and beam loadings, the total

[2] The boldface numbers in parentheses refer to the references appended to this paper.

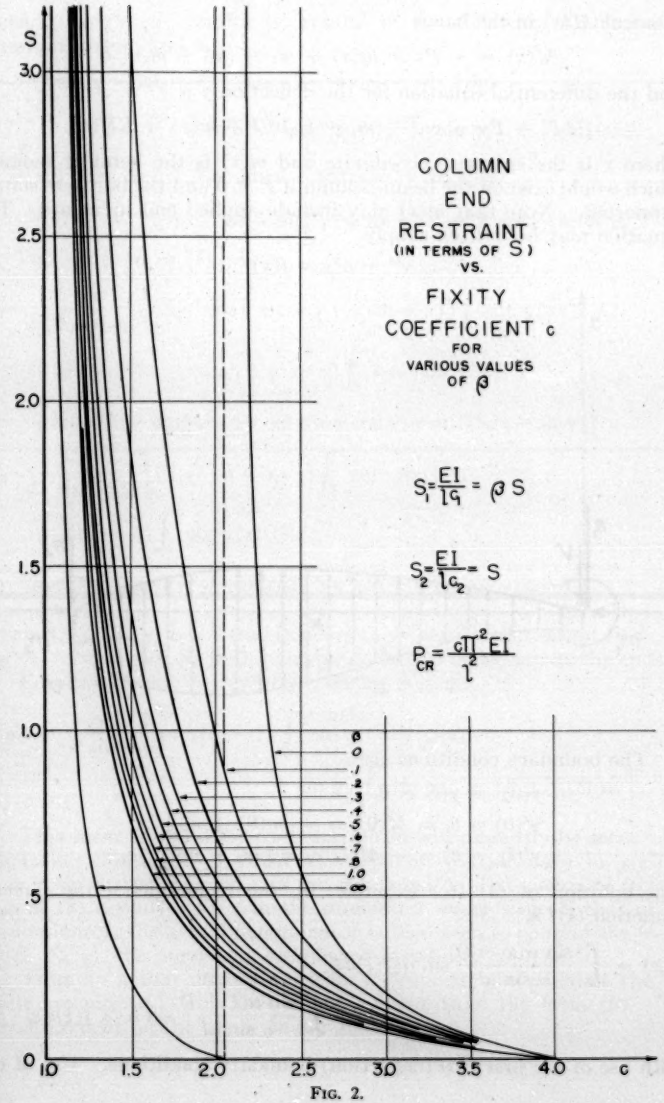
S
3.0
2.5
2.0
1.5
1.0
.5
0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
c
COLUMN
END
RESTRAINT
(IN TERMS OF S)
VS.
FIXITY
COEFFICIENT c
FOR
VARIOUS VALUES
OF β
$S_1 = \frac{EI}{lc_1} = \beta S$
$S_2 = \frac{EI}{lc_2} = S$
$P_{CR} = \frac{c\pi^2 EI}{l^2}$
0
.1
.2
.3
.4
.5
.6
.7
.8
1.0
∞

FIG. 2.

moment $M(x)$ in the bar is

$$M(x) = -Py + m(x) + m_1 - (m_1 + m_2)x/l, \tag{3}$$

and the differential equation for the deflection y is

$$EIy'' + Py = m_1 - (m_1 + m_2)x/l + m(x) = EIf(x), \tag{4}$$

where x is the spanwise coordinate and $m(x)$ is the bending moment which would exist on the beam-column if $P = 0$ and the bar were simply supported. Note that $m(x)$ may include applied end moments. The equation may be written simply

$$y'' + \alpha^2 y = f(x). \tag{5}$$

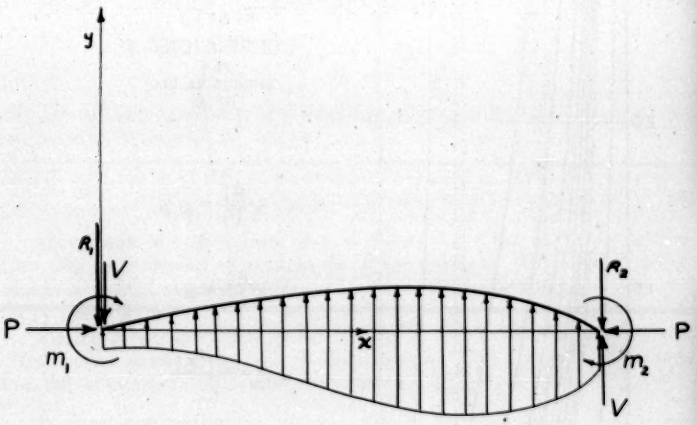

FIG. 3.

The boundary conditions are

$$\begin{aligned} y(0) &= y(l) = 0, \\ y'(0) &= \theta_1 = M(0)/c_1 = [m(0) + m_1]/c_1, \\ y'(l) &= \theta_2 = -M(l)/c_2 = [m_2 - m(l)]/c_2. \end{aligned}$$

The solution of (4) (for example, by the technique of the Green's Function (4)) is

$$y(x) = \int_0^x \frac{\sin \alpha(x - l)}{\alpha \sin \alpha l} \sin \alpha\xi f(\xi) d\xi + \int_x^l \frac{\sin \alpha(\xi - l)}{\alpha \sin \alpha l} \sin \alpha \times f(\xi) d\xi, \tag{6}$$

with use of the first two (deflection) boundary conditions. Use of the

second two (slope conditions) results in the following simultaneous equations for m_1 and m_2:

$$(-S_1\gamma^2 \sin\gamma - \sin\gamma + \gamma\cos\gamma)m_1 + (\gamma - \sin\gamma)m_2 = m(0)\gamma^2 S_1 \sin\gamma + \gamma^2 \int_0^1 \sin\gamma(1-\zeta)m(\zeta l)d\zeta,$$

$$(\gamma - \sin\gamma)m_1 + (-S_2\gamma^2 \sin\gamma - \sin\gamma + \gamma\cos\gamma)m_2 = -m(l)\gamma^2 S_2 \sin\gamma - \gamma^2 \int_0^1 \sin\gamma\zeta m(\zeta l)d\zeta. \quad (7)$$

The solutions of (7) are

$$m_1 = \frac{-\gamma}{D(S_1, S_2, \gamma)}\Big\{(S_2\gamma^2\cos\gamma + \cos\gamma + \gamma\sin\gamma - 1)\int_0^1 \sin\gamma\zeta m(\zeta l)d\zeta + (-S_2\gamma^2\sin\gamma - \sin\gamma + \gamma\cos\gamma)\int_0^1 \cos\gamma\zeta m(\zeta l)d\zeta + m(0)S_1(-S_2\gamma^2\sin\gamma - \sin\gamma + \gamma\cos\gamma) + m(l)S_2(\gamma - \sin\gamma)\Big\} \quad (8)$$

$$m_2 = \frac{-\gamma}{D(S_1, S_2, \gamma)}\Big\{(S_1\gamma^2 + 1 - \cos\gamma)\int_0^1 \sin\gamma\zeta m(\zeta l)d\zeta + (\sin\gamma - \gamma)\int_0^1 \cos\gamma\zeta m(\zeta l)d\zeta + m(0)S_1(\sin\gamma - \gamma) + m(l)S_2(S_1\gamma^2\sin\gamma + \sin\gamma - \gamma\cos\gamma)\Big\},$$

where $D(S_1, S_2, \gamma)$ is the transcendental instability expression, $D(S_L, S_1, S_2, \gamma)$, for the case $S_L = 0$, namely, no lateral deflection at the ends.

Equation 6 may be rewritten, letting $x = \eta l$:

$$y(\eta l) = \frac{\gamma}{P\sin\gamma}\Big\{\sin\gamma(\eta - 1)\int_0^\eta \sin\gamma\zeta[EIf(\zeta l)d\zeta + \sin\gamma\eta\int_\eta^1 \sin\gamma(\zeta - 1)[EIf(\zeta l)]d\zeta\Big\}. \quad (9)$$

This form is useful for computation as will presently be seen. Explanation should be given of the *apparent* discontinuity in $y(\eta l)$ at $\gamma = \pi$ since there is a $\sin\gamma$ in the denominator: Expression of $f(\zeta l)$ by use of (8) reveals a $\sin\gamma$ in the numerator which cancels that of the denominator; the actual denominator is then seen to contain the factor $D(S_1, S_2, \gamma)$, the previously established instability expression.

Thus no actual discontinuity in y exists at $\gamma = \pi$ unless the bar ends are pinned. This fact is not evident from the form (6). The total moment on the bar is finally given by

$$M(x) = M(\eta l) = -Py(\eta l) + EIf(\eta l). \quad (10)$$

III. PRACTICAL CALCULATION

Converting integrals to sums and taking, say, ten intervals, Eq. 9 may be rewritten approximately as

$$-Py(\eta l) = \frac{0.1\gamma}{\sin\gamma}\left\{\sin\gamma(1-\eta)\sum_{\zeta=0.05}^{\zeta=\eta}\sin\gamma\zeta[EIf(\zeta l)] + \sin\gamma\eta\sum_{\zeta=\eta}^{\zeta=0.95}\sin\gamma(1-\zeta)[EIf(\zeta l)]\right\} \quad (11)$$

for use in practical calculation.

Table I is a sample of a series of tables developed by the author to solve the beam-column problem for general loading conditions by practical calculation. The complete set of tables (not reproduced here) is calculated for $P/(P_{CR})_{PIN} = 0.1, 0.2, \ldots 0.8, 0.9, 1.2, 1.5, \ldots 3.9$, that is, covering the entire range of ratios of actual column load to critical load for the same column when pin-ended:

$$0 \leqq P/(P_{CR})_{PIN} \leqq 4.$$

Thus there were developed 19 tables in all. These tables are constructed to perform all the work implied in evaluating (11) with the exception of calculating $EIf(\zeta l)$ and summation. Such a set of tables can easily be constructed in any engineering department, following Eq. 11. Table I illustrates a property which aids in such construction, namely the symmetry of the tables about both diagonals.

A complete routine calculation procedure using such tables is outlined below, stepwise. Assumed given are EI, l, c_1, c_2, P and the lateral loading.

1. Calculate

$$(P_{CR})_{PIN} = \frac{\pi^2 EI}{l^2}.$$

2. Calculate

$$S_1 = \frac{EI}{lc_1}, \qquad S = S_2 = \frac{EI}{lc_2}, \qquad \beta = S_1/S_2.$$

NOTE: Choose $S_1 \leqq S_2$ above *except* when one column end is pinned ($S_1 = \infty$) and the other is elastically restrained ($S_2 \neq 0, \infty$). Then take $S_1 > S_2$ and $\beta = \infty$. (See text describing Fig. 2.)

3. Enter Fig. 2 with β and S as parameters and determine c, the column fixity coefficient.

4. Calculate

$$P_{CR} = c(P_{CR})_{PIN}.$$

5. Calculate

$$r = P/(P_{CR})_{PIN},$$
$$r' = P/P_{CR},$$

and

$$r = \pi\sqrt{r}.$$

TABLE I.—$P/(P_{CR})_{PIN} = 1.2$.

η	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95	$\gamma^2 \sin \gamma\eta$
0.05	0.02542	−0.04283	−0.10607	−0.15686	−0.18926	−0.19946	−0.18627	−0.15124	−0.09848	−0.03416	2.02795
0.15	−0.04283	−0.12348	−0.30576	−0.45219	−0.54559	−0.57501	−0.53699	−0.43600	−0.28390	−0.09848	5.84616
0.25	−0.10607	−0.30576	−0.46957	−0.69445	−0.83788	−0.88306	−0.82468	−0.66958	−0.43600	−0.15124	8.97816
0.35	−0.15686	−0.45219	−0.69445	−0.85530	−1.03196	−1.08760	−1.01569	−0.82468	−0.53699	−0.18627	11.05775
0.45	−0.18926	−0.54559	−0.83788	−1.03196	−1.10502	−1.16460	−1.08760	−0.88306	−0.57501	−0.19946	11.84060
0.55	−0.19946	−0.57501	−0.88306	−1.08760	−1.16460	−1.10502	−1.03196	−0.83788	−0.54559	−0.18926	11.23481
0.65	−0.18627	−0.53699	−0.82468	−1.01569	−1.08760	−1.03196	−0.85530	−0.69445	−0.45219	−0.15686	9.31155
0.75	−0.15124	−0.43600	−0.66958	−0.82468	−0.88306	−0.83788	−0.69445	−0.46957	−0.30576	−0.10607	6.92633
0.85	−0.09848	−0.28390	−0.43600	−0.53699	−0.57501	−0.54559	−0.45219	−0.30576	−0.12348	−0.04283	2.54279
0.95	−0.03416	−0.09848	−0.15124	−0.18627	−0.19946	−0.18926	−0.15686	−0.10607	−0.04283	0.02542	−1.50897

NOTE: (*a*) If $r' \cong 1$, the column is critical.

(*b*) If (*a*) is not the case but $r \cong \pi$ (that is, $r \cong 1$) calculate $M(x)$ separately by steps 6–10 for $r = 0.9$ and $r = 1.2$ and interpolate between final results for $M(x)$.

6. Draw the moment diagram $m(x) = m(\eta l)$ for lateral loading as if the beam-column were a simply supported beam with no column load. Note that ordinates of $m(\eta l)$ at the ten finite values of η are to be used:

$$\eta = 0.05, 0.15, 0.25, \cdots, 0.95.$$

7. Calculate m_1 and m_2 by solving simultaneously Eqs. 7 with the aid of Table I (or similar appropriate table). Except as noted in 5(*b*), interpolation between table entries is permissible. This involves merely numerical integration of the right hand integrals of (7) by the use of the "$\gamma^2 \sin \gamma\eta$" column appended to the right of the table. Use of the "$\gamma^2 \sin \gamma\eta$" column inverted will furnish values of $\gamma^2 \sin \gamma(1 - \eta)$. Note that m_1, m_2 are *reactive* end moments; they are not *total* end moments unless $m(x) = 0$ at the bar ends.

8. Draw the "generalized" moment diagram

$$EIf(\eta l) = m(\eta l) + m_1 - (m_1 + m_2)\eta.$$

9. With the values of $EIf(\eta l)$ at the ten abscissae 0.05, 0.15, 0.25, $\cdots$, 0.95, enter Table I (or similar appropriate table) using interpolated values according to the value of r if necessary. Multiply each table entry in the row "0.05" by $EIf(0.05l)$; multiply each table entry in the row "0.15" by $EIf(0.15l)$, etc. Add the resulting columns. The resulting row of sums represents $-Py(\eta l)$.

10. Draw the final moment curve

$$M(\eta l) = -Py(\eta l) + EIf(\eta l).$$

NOTE: For a pin ended column, with no external applied moments, $m_1 = m_2 = 0$; therefore, steps 2, 3, 4, 7 and 8 are omitted while other steps proceed as before. In step 5, $r = r'$; in step 9, $m(\eta l)$ replaces $f(\eta l)$ in this case.

The author has worked several examples and found good agreement between analytical results (in simple cases, where these are possible) and the method presented here. This method is not made more difficult by complex side loadings as is the analytical method. One example, using the sample table, Table I, is presented below.

Example:

Concentrated load Q at center. Column ends partially restrained.

c_1 = 4000 in. lb. per radian, $EI = 2 \times 10^8$ lb. per sq. in.,
c_2 = 3000 in. lb. per radian, l = 100 in.
P = 236 lb.,

The calculation follows steps 1–10 above.

1. $(P_{CR})_{PIN} = 197$ lb.
2. $S_1 = 0.5$; $S_2 = 0.6667$; $\beta = 0.75$.
3. From Fig. 2, $c = 1.6$.
4. $P_{CR} = 1.6 \times 197 = 315$ lb.
5. $r = 1.2$; $r' = 0.75$; $\gamma = \pi \times \sqrt{1.2} = 3.45$.
   (*a*) Column is not critical.
   (*b*) No interpolation is needed; the table for $r = 1.2$ can be used directly.
6. $Q = 10$ lb.

η	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95
$m(\eta l)$	27	75	125	175	225	225	175	125	75	25

7. Equations (31) are:

$$-1.199m_1 + 3.75m_2 = 1130.9,$$
$$3.75m_1 - 0.599m_2 = -1130.9.$$

The solutions are:

$$m_1 = -267.04 \text{ in. lb.},$$
$$m_2 = 216.19 \text{ in. lb.}$$

8.

η	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95
$EIf(\eta l)$	−239.5	−184.4	−129.3	−74.2	−19.2	−14.1	−59.0	−103.9	−148.8	−193.7

9.

	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95
0.05	−6.09	10.26	25.40	37.57	45.33	47.77	44.61	36.22	23.59	8.18
0.15	7.90	22.77	56.38	83.38	100.61	106.03	99.02	80.40	52.35	18.16
0.25	13.71	39.53	60.72	89.79	108.34	114.18	106.63	86.58	56.37	19.56
0.35	11.64	33.55	51.53	63.46	76.57	80.70	75.36	61.19	39.84	13.82
0.45	3.63	10.48	16.09	19.81	21.22	22.36	20.88	16.95	11.04	3.83
0.55	2.81	8.11	12.45	15.34	16.42	15.58	14.55	11.81	7.69	2.67
0.65	10.99	31.68	48.66	59.93	64.17	60.89	50.46	40.97	26.68	9.25
0.75	15.71	45.30	69.57	85.68	91.75	87.06	72.15	48.79	31.77	11.02
0.85	14.65	42.24	64.88	79.90	85.56	81.18	67.29	45.50	18.37	6.37
0.95	6.62	19.08	29.30	36.08	38.64	36.66	30.38	20.55	8.30	−4.92
	81.57	263.00	434.98	570.94	648.61	652.41	581.33	448.96	276.00	87.94

10.

0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95
−157.9	78.6	305.7	496.7	629.4	638.3	522.3	345.1	127.2	−105.8

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APPENDIX

List of Symbols

x, y	Abscissa and ordinate of point in loaded bar.
V	Vertical reaction at ends of bar (lb.).
δ_1, δ_2	Vertical deflection of linear springs at left and right hand ends of bar (in.).
k_1, k_2	Spring constants of linear springs at left and right hand ends of bar (lb. per in.).
m_1, m_2	Reactive moments at ends of bar under load.
c_1, c_2	Spring constants of torsional springs at left and right hand ends of bar (in. lb. per radian), that is, "end restraint coefficients" of bar.
θ_1, θ_2	Angular rotations of left and right hand ends of bar under load (radian).
P	Column load on bar (lb.).
l	Length of bar (in.).
$M(x)$	Bending moment on bar at any section x (in. lb.).
$m(x)$	Bending moment (in. lb.) on bar under transverse load when considered as a simple beam.
E	Elastic modulus of bar material (lb. per sq. in.).
I	Moment of inertia of any bar section (in.^{4}).
α	Defined by $\alpha^2 = P/EI$.
c	Column restraint coefficient appearing in Euler column formula for P_{CR}.
P_{CR}	Critical instability load on bar with general end restraints (lb.) defined by $\frac{c\pi^2 EI}{l^2}$ (Euler formula).
$(P_{CR})_{PIN}$	Critical instability load on bar with pin end restraints (lb.).
$S_1, S_2 = S$	Dimensionless "reciprocals" of end restraint coefficients c_1, c_2 defined by $$S_1 = \frac{EI}{lc_1}, \qquad S_2 = \frac{EI}{lc_2}.$$
S_L	Dimensionless parameter involving reciprocals of k_1, k_2 defined by $$S_L = \frac{EI}{l^3}\left(\frac{1}{k_1} + \frac{1}{k_2}\right).$$
γ	Dimensionless parameter defined by $\gamma = \alpha l$.
$D(S_L, S_1, S_2, \gamma)$	Transcendental stability expression involving dimensionless parameters. (See Eqs. 2 and 8.)
$D(S_1, S_2, \gamma)$	
β	Ratio of S_1 to $S_2 = S$ (Fig. 2).
ξ	Auxiliary variable having dimensions of inches, same range as $0 \leqq x \leqq l$.

ζ Auxiliary dimensionless variable having range $0 \leqq \zeta \leqq 1$.

η Auxiliary dimensionless variable having same range as ζ.

Q Concentrated bar transverse load (lb.) used in example.

$r = \dfrac{P}{(P_{CR})_{PIN}}$.

$r' = \dfrac{P}{P_{CR}}$.

Weston's Relative Humidity Indicator Now Has a Fan Attachment.—Accurate humidity readings can now be obtained quickly in factories, shops, rooms and even small, confined spaces near, or in operating machinery, thanks to a new motor-operated fan developed for attaching to any Weston Relative Humidity Indicator.

The small fan, powered by dry cells, will move air over the indicator's wick in sufficient volume to permit obtaining stable readings within 30 seconds. This makes possible complete analysis of humidity conditions in, for example, a textile mill, particularly in and around the machinery while it is operating, thus enabling the adjustment of the humidifiers and air-conditioning equipment for best results.

No calculations are required, as readings are immediately obtained on the instrument's simplified slide rule.

Weston Relative Humidity Indicators are now available with or without the auxiliary fan, or the auxiliary fan can be purchased separately. Complete information may be obtained from the Weston Electrical Instrument Corporation at 617 Frelinghuysen Avenue, Newark 5, N. J.

Fresh Orange Juice Keeps Flavor on Long Trips to Market.—Fresh, refrigerated orange juice, prepared and packaged by a new process, is now being shipped commercially from citrus-producing areas to distant markets without loss of flavor or other qualities, the U. S. Department of Agriculture announces.

Ordinarily, orange juice would lose much of its flavor after only a few days in transit and storage. But Bureau of Agricultural and Industrial Chemistry researchers at Pasadena, Calif., working in cooperation with citrus processors, have devised a large-scale, commercial method for producing and packing the juice so that it retains good taste quality and vitamin-C content for two weeks or longer. Even after 3 weeks in refrigerated storage, this product is superior to heat-processed canned orange juice.

Development of the new process, which provides an additional means of moving the country's increasing crop of healthful oranges into economical consumption, was undertaken in 1946 by Dr. E. A. Beavens, in charge of the Bureau's new Pasadena Research Laboratory, and one of his associates, Dr. J. C. Underwood. Most of their work was done at the laboratory maintained by the Bureau until recently at Los Angeles. Object of this research was to find a way to protect the flavor and nutritional quality of fresh, unpasteurized, single-strength orange juice for a period long enough to permit wide distribution.

The method now in commercial use involves careful reaming of the fruit, so that very little peel oil gets into the juice. Too much of this oil will hasten development of off-flavors. The prepared juice is quickly chilled to 30 degrees Fahrenheit and kept at this temperature until used.

Carload lots of this fresh orange juice, packed in 1-gal. cans and refrigerated with ice and salt, have been shipped successfully from Los Angeles to New York City. The present production in southern California, which amounted last year to almost 2½ million gallons, is currently distributed to nearer cities. Ten plants of varying size are now using the process on a year-round basis in California. A large part of their output is shipped by refrigerated truck to consumers within a radius of 500 miles.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS *

NEW USES FOR MAGNETIC FLUIDS

The magnetic fluid originally used in the electromagnetic fluid clutch developed at the National Bureau of Standards has several unique features that make possible other important applications of iron-oil mixtures. Further studies of the properties of these mixtures have revealed that magnetic fluids can be employed to good advantage in hydraulic systems, shock absorbers, and dash pots; to form casting molds; and as variable electrical resistors. The basic property on which all these applications depend is that the viscosity of a magnetic fluid is directly related to the strength of the applied magnetic field—the fluid may be changed from a liquid to a nearly solid state and back again at will.

In some applications extreme fluidity is required at all times, while in others a thixotropic characteristic is needed. Thixotropic fluids are characterized by isothermal reversible gel-sol-gel transformations under shearing and subsequent resting. Mayonnaise, a good example of a thixotropic fluid, resists flow when its container is turned over, but may be stirred easily with a spoon. Honey, a nonthioxtropic material, flows like all ordinary fluids but, because of its high viscosity, resists stirring.

When a magnetic fluid is used in a nonrotating device, the iron particles in the mixture must remain in suspension and not settle out. One way of achieving this is to use a thixotropic fluid. Another way is to maintain a small magnetic field in the mixture during idle periods. In rotating machinery, settling is less important as long as the iron powder can be readily remixed with the fluid. This can be achieved by adding a surface-active ingredient to the iron-oil mixture.

One engineering application proposed in the Bureau's preliminary investigation of new uses for magnetic fluids is the magnetic fluid dash pot. Basically, a dash pot consists of a piston moving in a fluid-filled cylinder with the viscosity of the fluid resisting the piston motion. In a conventional dash pot the rate of travel of the piston is determined by the external force, the fluid pressure on the piston, the dimensions of the fluid escape vent, and the fluid viscosity. Although the viscosity of the fluid depends to a large extent on its temperature, the speed of piston travel is not ordinarily regulated by controlling temperature. The only variable usually controlled is the pressure on the piston. The rate of piston travel can be adjusted mechanically by providing a variable orifice in the piston or in the cylinder wall—a method that presents a number of complications.

* Communicated by the Director.

On the other hand, if a magnetic fluid is used in the dash pot the rate of motion of the plunger can be readily controlled by magnetically varying the viscosity of the fluid. If a coil of wire is placed around the dash pot, the viscosity of the magnetic fluid will be a function of the current in the coil. Employing this idea in the design of shock absorbers for automobiles and trucks would provide an adjustable riding quality to meet various loading and roadway conditions. The rate or response of the magnetic fluid is high enough to provide virtually instantaneous changes in viscosity, thereby making possible a shock absorber with automatic compensation.

The electromagnetically controllable fluid offers interesting possibilities for use in hydraulic systems. If a hydraulic system is filled with a magnetic fluid, valving becomes extremely simple: By winding a coil of wire around a fluid-carrying pipe and controlling the amount of current through the coil, the flow of fluid past that point can be closely regulated from full flow to complete cut-off. An obvious advantage of this scheme is that various points in a hydraulic system can be remotely controlled from a central station.

Electromagnetic fluids are also being investigated for use in molding operations. A fluid is placed in a pot surrounded by a current-carrying coil, a model of the part to be cast is placed in the fluid, and the coil is then energized so that the fluid will solidify around the model. When the model is removed, a detailed impression remains outlined in the solidified magnetic fluid. Molding compound can then be poured into the mold and allowed to harden. After the coil current is turned off the molded replica can easily be removed from the liquid. In any application of this kind, the boiling point of the magnetic fluid must of course be higher than the temperature of the molten casting material.

An electrical resistor adapted to remote control can be made by immersing two electrodes in a magnetic fluid. When the fluid is in an unmagnetized condition, the resistance between the two electrodes will be extremely high because of the very loose contact among the conductive iron particles that are randomly distributed in the nonconductive oil. In the presence of a magnetic field, however, the iron particles apparently form chains along the lines of magnetic flux and draw into close physical contact. The flux density will determine the massiveness of the chain and, thus, the conductivity of the mixture. When the system is de-energized, the conductance does not drop back to its former very low level. This property of magnetic fluid resistors is attributed to the coherer effect that has been previously investigated by Branley, Marconi, and others.

The success or failure of any device utilizing magnetic fluid will depend to a considerable extent on the particular components in the iron-oil mixture, the choice of suspension fluid and iron powder in large measure being determined by the application for which the mixture is

intended. The iron powder is one component of the mixture not generally varied from one application to another, since certain properties are considered essential for satisfactory operation: In order to achieve maximum magnetic efficiency the iron powder must have high permeability; to minimize wear and abrasion on moving parts the particles should have smooth, continuous exteriors; and the iron powder must be chemically stable, resisting oxidation in the suspension fluid.

In mixtures where it is essential to prevent settling and sedimentation, the particles should be of uniform size and no larger than about 20 microns in diameter. A great many powders have been tried at the National Bureau of Standards including pure iron, alloys, oxides, and ferrites. The powder which has proven most universally successful is a carbonyl iron in the form of particles about 8 microns in diameter.

The choice of a suspension fluid is not so simple. Some of the factors which must be considered are chemical stability, flammability, vapor pressure, and viscosity. In any magnetic fluid device where there is considerable mechanical movement, the viscosity of the suspension fluid may be especially important, and if it is desirable to hold the viscous drag at a low value during non-energized periods, a low-viscosity fluid must be used. The fluids must also be chemically stable in the presence of the iron powder, and should not become sticky or gummy at high temperatures.

In earlier experiments at the Bureau it was found that many ordinary lubricating oils have enough sulfur in them to cause rapid oxidation and clumping of the iron particles. It was also found that many animal oils (including lard or sperm) tend to catalyze and become gummy and solid. One type of fluid that is remarkably stable in the presence of iron powder is a silicone liquid that has a viscosity of around 50 centistokes at 25 degrees Centigrade. It is excellent with respect to nonflammability and vapor pressure, and this versatile fluid will serve satisfactorily in nearly all but extremely high temperature applications. When it is necessary to operate a magnetic fluid device at elevated temperatures, special compounds such as fluorinated and chlorinated fluids can be used, but special precautions must be taken with the seals since the vapors from these fluids are quite toxic.

Government-sponsored Research. (Excerpt from Address by Karl T. Compton, Chairman, Research and Development Board, before the Executives' Club of Chicago).—Out of every dollar which you now pay in federal taxes, a little more than one cent is spent for research and development to provide more effective weapons, equipment, medicines and utilization of human resources for our national defense. Stated in another way, research and development takes a little less than four cents our of every dollar spent for our Military Establishment.

As citizens and taxpayers, you are rightly interested in the efficiency with which this money is used and the value of the results for which it pays. Are we spending enough or too much on this aspect of national security? What measures are being taken to evaluate these questions and to provide competent guidance and administration? These are questions which I welcome the opportunity of discussing with you today.

Let me first explain that the sum of approximately $550,000,000 about which I am speaking does not include the sums separately provided by Congress to the Atomic Energy Commission for its very important research and development program. These amount, for total contract authority in the current year, to about $150,000,000 and it is rather difficult to assign specific proportions of this to research and development versus production, or to military as opposed to peacetime purposes. It can be said that most of the research in this field, whether initially stimulated for military or non-military purposes, is applicable to both.

By a rough estimate, eighty per cent of all the expenditures under the atomic energy program could be justified by purely non-military objectives even though a considerable portion is now going into the production of atomic bombs. This is because the materials uranium and plutonium which are produced for atomic bombs are also the materials required for the production of atomic energy. If the happy time comes when we can "beat our swords into plowshares," then the stockpile of atomic bombs can be converted into the fuel for atomic power plants by methods which are now being developed within the program of the Atomic Energy Commission, and which should be operating in the early experimental pilot-plant stage within a couple of years.

THE FRANKLIN INSTITUTE

PROCEEDINGS OF THE 125TH ANNIVERSARY OF THE FOUNDING OF THE FRANKLIN INSTITUTE AND THE CELEBRATION OF THE 200TH ANNIVERSARY OF FRANKLIN'S ELECTRICAL EXPERIMENTS

April 20, 1949

Afternoon Session

At 2:00 P.M. a joint meeting of The Franklin Institute and the American Philosophical Society was held in the Lecture Hall. Mr. Richard T. Nalle, President of the Institute, graciously welcomed the members and their guests, among whom were many members of the American Philosophical Society, founded by Benjamin Franklin. The greetings of this Society were formally extended to the Institute by Dr. Edwin G. Conklin, President, in a short address whose text appears below. Dr. Robert A. Millikan then spoke about Benjamin Franklin, the printer, the businessman, the scientist and the statesman, emphasizing the importance of his electrical experiments. Dr. Millikan's talk is printed below. The session closed with an informative, illustrated lecture by Mr. C. Guy Suits, Vice-President of General Electric Company and Director of its Research Laboratories in Schenectady, on the subject "A Progress Report on American Research." Since this talk was based on a series of camera slides, it is not feasible to publish it in the JOURNAL. Following the meeting in the Lecture Hall, guided tours through the Museum and the Laboratories were arranged for those who were interested.

GREETINGS OF THE AMERICAN PHILOSOPHICAL SOCIETY TO THE FRANKLIN INSTITUTE ON THE 125TH ANNIVERSARY OF ITS FOUNDATION AND ON THE 200TH ANNIVERSARY OF BENJAMIN FRANKLIN'S ELECTRICAL EXPERIMENTS

EDWIN G. CONKLIN

President of the American Philosophical Society

I have been asked to bring the greetings of the American Philosophical Society to The Franklin Institute of Pennsylvania on this one hundred and twenty-fifth anniversary of the founding of the Institute. I am very happy to do this because the American Philosophical Society is proud to recognize The Franklin Institute as one of its daughters, or step-daughters, or younger sisters—at least a close relation—in the origin of which it played a part. Both the American Philosophical Society and The Franklin Institute have the same Patron Saint. Benjamin Franklin was the founder of the American Philosophical Society, its first Secretary, President for twenty-one years, chief contributor to its building, publications, library, and its European reputation. In the first Annual Report of The Franklin Institute six officers and twenty-four managers are listed. Both Vice-presidents and the Recording Secretary and Chairman of the Board, Editor of *The Franklin Journal* were members of the American Philosophical Society. Six of the twenty-five persons who are listed as chief founders of The Franklin Institute in Dr. Sidney L. Wright's "Story of The Franklin Institute" were members of the American Philosophical Society, *viz.* William H. Keating, Clement C. Biddle, Mathew Carey, George Fox, Thomas Gilpin, and Robert Harris, while ten others of these officers, members, and committee men, *viz.* Robert M. Patterson, William Strickland, Isaiah Lukens, Alexander Dallas Bache, James Rush, Robert E. Griffith, Matthias W. Baldwin, Thomas McEwen, Samuel Vaughan Merrick, and Frederick Fraley, soon after became members or officers of the American Philosophical Society. Merrick was the prime mover among these

founders in organizing the Institute; Robert M. Patterson was the eighth President of the American Philosophical Society; Bache, great grandson of Franklin, was the first President of Girard College and of the Central High School of Philadelphia, and twelfth President of the American Philosophical Society; while Frederick Fraley was the fifteenth President of the Society.

When Samuel Vaughan Merrick issued the first call for a meeting of those persons interested in what was to be virtually a technical high school, the place of meeting was specified as "Philosophical Hall." Unfortunately, no people attended this meeting and another meeting was called a few days later which was similarly neglected by the public, but on the ninth of December, 1823, Mr. Merrick, who was himself a young industrialist of Philadelphia, twenty-two years old, together with William H. Keating, Professor of Chemistry at the University, held a successful meeting of about a dozen citizens in the Hall of the American Philosophical Society and on this occasion they drew up a constitution and appointed a committee on membership. On February 5, 1824 a large general meeting was held in the County Court House, which is now known as Congress Hall, and the constitution of The Franklin Institute was adopted, and an invitation to join the Institute was followed by the acceptance of four or five hundred persons as members. This was the actual beginning of The Franklin Institute of Pennsylvania and it proceeded immediately in that year, 1824–25, to undertake the work for which it was organized, to secure a charter from the Legislature of the State, and to build the home of the Institute on Seventh Street between Market and Chestnut, which building it occupied for more than one hundred years, until it built and occupied the present magnificent structure on the Benjamin Franklin Parkway at Twentieth Street. This was intended to be, and indeed is, the greatest structural memorial to Benjamin Franklin in Philadelphia, though his name is associated with many of the scientific, educational, and humanitarian organizations of the city.

The earliest activities of the Institute consisted of lectures and classes on "Mechanic Arts" and the Institute was known as "Franklin High School" before there was any other high school in Philadelphia. Members were largely scientists, inventors, and business men, and their number was not limited, whereas the members of the American Philosophical Society were to be "Virtuosi or ingenious men" and the number of living members has never been more than five hundred. Indeed, the American Philosophical Society was modelled on the Royal Society of London and was intended by Franklin to be a kind of Royal or Premier Society of America. The Academy of Natural Sciences of Philadelphia, like The Franklin Institute, has no specific limit in numbers and its members have been largely naturalists and medical men interested in the scientific aspects of anatomy, biology, and physiology.

It may be useful to indicate the course of cultural differentiation which is presented by some of the organizations which have grown out of the American Philosophical Society, or which at least were stimulated by the Society in their early years. Franklin indicated in his call for the founding of the Society, "A Proposal for Promoting Useful Knowledge among the British Plantations in America," which was issued in 1743, that the membership should consist of "Virtuosi or ingenious men residing in the several Colonies" who were to "maintain a constant Correspondence." The subjects of the correspondence were to be: "New-discovered Plants . . . &c. their Virtues, Uses, &c. Methods of Propagating them . . . Improvements of vegetable Juices, as Cyders, Wines, &c.; New Methods of Curing or Preventing Diseases. All new-discovered Fossils in different Countries, as Mines, Minerals, Quarries; &c. New and useful Improvements in any Branch of Mathematicks; New Discoveries in Chemistry, such as Improvements in Distillation, Brewing, Assaying of Ores; &c. New Mechanical Inventions for saving Labour; as Mills, Carriages, &c. and for Raising and Conveying of Water, Draining of Meadows, &c.; All new Arts, Trades, Manufactures, &c. that may be proposed or thought of. Surveys, Maps and Charts of particular Parts of the Sea-coasts, or Inland Countries; Course and Junction of Rivers and great Roads, Situation of Lakes and Mountains, Nature of the Soil and Productions; &c. New Methods of Improving the Breed of useful Animals, Introducing other Sorts from foreign Countries. New Improvements in Planting, Gardening, Clearing Land &c.; And all philosophical Experiments

that let Light into the Nature of Things, tend to increase the Power of Man over Matter, and multiply the Conveniences or Pleasures of Life."

This was really a program of promoting all useful knowledge and its applications. Before the establishment of the Patent Office all sorts of inventions were reported to the Society, such as a machine for mowing with a horse, various improvements in ships and electrical rods or lightning conductors, description of a speedy elevator, methods of destroying pernicious insects, a new and simple nautical chart, improved hydrants and street lamps, and many other such practical applications of science to man's comfort and welfare which are now handled by many Government bureaus and private institutions.

The first Fund of the Society was established in 1786 by the gift of 200 guineas by John Hyacinth de Magellan, of London, for a gold medal to be awarded annually to the author of the best discovery or most useful invention in some of the fields which I have indicated.

But the American Philosophical Society was more than a stimulator of practical inventions for, like its founder, it also had a particular interest in what may be called the foundations of science and discovery or what in the eighteenth century was known by the name of "philosophy." It was particularly interested in the last of the "subjects of correspondence" listed above, namely "All philosophical Experiments that let Light into the Nature of Things, tend to increase the Power of Man over Matter, and Multiply the Conveniences or Pleasures of Life," and it is this part of Franklin's original program for the American Philosophical Society that today represents its principal function.

At present the fields represented by members of the American Philosophical Society are Mathematical and Physical Sciences, Geological and Biological Sciences, Social Sciences, and the Humanities, and the present functions of the Society are represented chiefly in the following standing committees, *viz.* the Committees on Finance, Meetings, Publications, Library, and Research. With the growth of the resources of the Society, chiefly in the present century, it has been possible to enlarge greatly the activities of the Society in all of these fields, and especially in the last named. The Society now allots grants for research in all fields of learning to a total sum of about $100,000 per year.

In 1812 naturalists and medical men of Philadelphia, and of the United States in general, organized the Academy of Natural Sciences of Philadelphia. Many leading members of the American Philosophical Society joined in this organization and over the course of the following century the Society turned over to the Academy its entire Cabinet of Natural History including many invaluable specimens collected and presented to the Society by Thomas Jefferson, Casper Wistar, and other distinguished members.

In 1824 the Historical Society of Pennsylvania took over in large part the functions of the Historical and Literary Committee of the American Philosophical Society, and in the same year The Franklin Institute took over much of the work of the Committee on Mechanics and Architecture and of another Committee on Trade and Commerce.

The early collections of the Society in archaeology and ethnology have been placed on permanent loan with the University Museum, and many volumes of the Library, in technical and special fields, no longer cultivated by the Society, have been distributed to other libraries in Philadelphia and elsewhere where they will be of greater service. Thus the functions and collections of this oldest learned society of America have gradually been distributed to these younger and more specialized organizations.

The American Philosophical Society felicitates The Franklin Institute on this auspicious birthday; it, in company with the world of science, congratulates the Institute on the notable contributions which it has made to science and civilization; it confidently anticipates in coming centuries and quarter-centuries still greater achievements in the service of man; and the Society hails the Institute with a hearty *God Speed!*

There is a fascination about Centennials that derives in part from the ease of marking off the constant flow of time in round numbers, and from the blessings of the decimal system for those who have difficulties with more complicated numerals. Such centennials also call attention in a striking way to the progress of civilization in successive periods of equal duration, and they furnish inspiration and call for new dedications for centuries to come. They are also

occasions of Campaigns for Centennial Funds, which sometimes, unfortunately, have *Tencential* results.

The first Centennial of which I have any recollection, although I was not present at the Celebration and followed the description of events only in the newspapers, was the great Centennial Celebration of American Independence in this City in 1876. Its influence on the progress of science and learning in America was simply incalculable. The effects of the Sesqui-Centennial Celebration of 1926 were not so great, although the progress of Civilization was probably greater in that half-century than in the previous century. But the rapid progress of science in the fraction of a century, indeed in a single lifetime, calls for looks backward and forward in every half- or quarter-century.

But in the endless flow of time how insignificant years, and lifetimes, and even centuries seem! And how devoutly we should echo Whittier's *Centennial Hymn:*

"Our father's God! from out whose hand
The centuries fall like grains of sand,
We meet today, united, free,
And loyal to our land and Thee,
To thank Thee for the era done,
And trust Thee for the opening one."

BENJAMIN FRANKLIN AND HIS ELECTRICAL EXPERIMENTS

DR. ROBERT A. MILLIKAN
California Institute of Technology

I have been asked to say something about Franklin on this double occasion for honoring him, but you will all agree that it is impossible to say something new about Franklin. There is no one who would challenge that statement. There is no American, living or dead, about whom so much has already been said and written as about Benjamin Franklin. I doubt whether any man has ever lived, other than the founder of a religion, whose name is so widely known as that of Benjamin Franklin. So what I shall attempt to do is merely to analyze why it is that Franklin has such publicity value.

There is one cause of his great notoriety for which he deserves no particular credit—call it the "Adam cause." In other words, the first man who enters any field and does things in it is always a very marked man. It can't be otherwise. Franklin was in fact the first man who ever did anything in the field of electricity that was analytical or that helped man in any way to understand this most destructive and amazing phenomenon of the natural world. Our age being the electrical age, it is inevitable and proper that Franklin should have a great part in celebrations having to do with the beginnings of "the age of electricity."

Benjamin Franklin is directly comparable with Sir Isaac Newton or should I say with Copernicus who is credited with the initiation of the great Copernican theory. How much he deserves credit for the whole of it is perhaps debatable. For Sir Isaac Newton certainly was the first in understanding the action of gravity. So both of them were "Firsts." Again in our own time, Roentgen has very wide notoriety primarily because of the fact that he was a First, that it was so thrilling a thing to all mankind to realize that there was such a thing as seeing your own skeleton, which is what Roentgen did. That type of publicity is a thing that is more or less accidental, but if you want, in order to understand the full scope of the popularity of Franklin, I'll have to give at least a "Who's Who" kind of a sketch of Franklin's life, which I shall divide into four periods.

The first period is from birth to the age of 17, and even then there were some things that were notable for which he had no responsibility—he was the 17th child, which is a thing that is quite out of the ordinary, and for which he certainly had no responsibility. He had no formal education, his only contact with the public schools being in the two years from age eight to age ten. At age 10, he became a printer's apprentice and, due to his own inner qualities, a master printer before he was 17. Not only did he become a master printer, but he began in those

seven years to cultivate the art of expression, studying English models that he might become a good writer, so that at 17 he was a master printer and a young publisher also.

That takes us to the second period of his life, which I call the period of the successful business man. That period lasted from the age of 17 up to the age of 42. It starts by his leaving Boston, taking a ship to New York and then getting over to Philadelphia with a few shillings in his pocket, mostly by walking. That shows some of the qualities in the man. Then when he got to Philadelphia, practically instantly, within a few months, he showed his geniality and his genius for making friends by having in the City of Philadelphia—I believe its population was the great number of 10,000 at that time—the friendship of the governor, Keith, who actually persuaded him to go to England in order to buy material for setting up a master printer's workshop in Philadelphia. Franklin went to England and stayed there for two years, but Keith, his patron, went back on him. This did not hurt him at all because he was already a master printer and could get work in printing, which he did, paying no attention to the fact that his patron had gone back on him. He returned to Philadelphia and started over again at the age of 20, becoming very rapidly the leader of the whole printing and publishing business in the colonies and dominating completely that field. Let me see if I can give you one or two illustrations of his diversified activities in that second period of his life.

When he was only 25 years old, he started "Poor Richard's Almanac" as a part of his venture and had an enormous circulation in the colonies with that Almanac. As a result of the profitableness of his publishing business, by the time he was forty-two he was ready and determined to retire and to do some things other than to make a living for himself and his family.

But even while he was making that living he was doing civic things. At the age of 25 he started the first circulating library in the new world. At the age of 30 he became a member of the General Assembly and he also organized the first Police and Fire Department in the Colonies. At about the same age, 30 or 31, he was active in founding a hospital and at almost the same time, probably a little later, he founded also the debating society which became the Philosophical Society, and also an academy which later became the University of Pennsylvania.

He was ready to retire at the age of 42 on the income from his publications. He had the sense to make a partnership, "Franklin and Hall," turning over the work to Hall but keeping a proper share of the income of the firm. He not only did that here in Philadelphia but also in New York. His partner in New York ran the business and Franklin's part of the proceeds was properly arranged so that when he retired he had an income of three thousand pounds a year, that is fifteen thousand dollars, which at the present value of American currency would be equal to fifty thousand dollars in buying power. That is then the brief history of Franklin as the successful business man.

The next period is the period of his scientific work. There were only seven years of it, for he started in 1747 and in 1753 he was taken away from his experiments and went into the last period, his political one, which lasted the rest of his life. It was in the scientific period that his great fame and publicity came, for he became at once a world figure, not merely a Colonial figure, because of the lightning rod incident.

The Lightning Rod incident began in 1750 with a letter to Peter Collinson, in which he described a way to prove that electricity, produced by rubbing a glass rod with silk, was the same thing as lightning. He wrote this letter suggesting that on some tall tower in Europe they put up a rod and collect the electricity from the clouds and store it in a Leyden jar. The paper was read in the Royal Society of London and completely shelved, if not laughed at. By some good fortune, the report about it got over to France and King Louis the Fifteenth had the sense to ask one of his subordinates to try the experiment. It was tried in Paris and it succeeded. At once Franklin became a world figure, for everywhere all over the world the experiment was repeated. In Russia in trying to repeat it one man was killed.

There came at once, naturally, the kind of publicity that comes from harnessing lightning—the most terrifying and the most awful phenomenon of nature. When it was learned that one man had tamed the lightning, and begun to understand it, the publicity value of that situation was infinite. Franklin was at once a man known the world over througout the rest of his life.

Because of the success of the Philadelphia experiment, performed in Paris, he was made a member of the Royal Society of London in 1753 and in the same year a member of the Paris Academy.

Scientific honors the world over were his. The kite experiment came two years after. It is the same thing as what had become known as the Philadelphia Experiment. It was simply another way of getting a sharp point up into the clouds. But at any rate, it got into the text books of every nation as Franklin's Kite Experiment, so that there is no wonder that Franklin's publicity value probably exceeds any other man living or dead, save that of those who have founded religions.

Franklin stopped his experimenting with electricity in 1753 and entered local politics for about four years, not too successfully. In 1758 now being a world figure, he was naturally chosen by the colonies to go to England, particularly because of the fact that he knew England so well from his earlier contact there. Save for two years, he was in England from 1758 to 1776 during which time he worked not as a master printer but rather worked with the British Government, trying to adjust things between the colonies and King George. By the way, one of the amusing incidents of that period is that inasmuch as it had been decided to place lightning rods on the top of Westminster and also on the Buckingham Palace—King George insisted that they be terminated by balls instead of points and there was a quarrel over that demand, an incident which shows how badly power is often misplaced in human affairs.

There is nothing further that I am going to add until 1776, when Franklin was sent as one of three commissioners to Paris to sell the case of the Colonies to what was then unquestionably the greatest monarchy on earth, namely that existing in France. And as everybody knows, he was able to adapt himself; whether it was in kissing the ladies of the court or whether it was in dealing with the qualities on the masculine courtiers, he showed himself a successful diplomat. He kept his press going in Passy too, so that to the end of his days he remained a master printer, and publisher. The last trip that he made to get back to this country was a very, very bothersome one because the days were long and he suffered a great deal from a stone in his bladder. I don't think they operated or that he had any relief from the pain of that stone, but he was here at home for five years, and in spite of his infirmities exerted an important influence in the constitutional convention. He died in 1790.

At his funeral the various societies which had been organized by him cast lots to see who should have the place of honor at his funeral. I think the Philosophical Society won first place and the University of Pennsylvania got second place. What they did, however, was to withdraw and let the Society of Printers go first, because they thought, properly, that it would please Franklin most that they should go first. He wanted to be known from the time he started to the time he died as Franklin, the printer and publisher.

Now, I don't want to close without presenting you with that which isn't only *about* Franklin but that which *is* Franklin. I suspect that a large number of this audience, if they have read the letters to Peter Collinson, will have forgotten them, and a large number of my audience will never have read them anyway. So, I want to read a few paragraphs from the first letter written when nobody knew anything whatsoever about electricity. Before Franklin only a few things had been discovered in that field. The rubbing of amber by Thales in 600 B.C. was the first, and not another thing appears until 1600 A.D., when Gilbert repeated the Thales experiment and showed that you could get the same effects with substances other than amber. A 100 years later, Stephen Gray discovered the facts of conductivity and then DuFay, a Frenchman, showed there were two kinds of electricity but he differentiated them only because he found attractions in one place when he found repulsions in another and therefore labeled them vitreous (or glass) electricity and resinous electricity after the two substances rubbed. He got what we now call electricities of a positive sign and of negative sign. Further, the so-called Leyden jar was accidentally discovered by Musschenbroeck in Holland in 1745, just at the time at which Franklin was arranging to retire. It was because of the fact that one could get larger shocks from a Leyden jar than one could get from a rubbed rod of glass or ebonite that electricity became quite a plaything of the courts, because one could shock another person more powerfully that way. Now comes the first letter of the Peter Collinson series by Franklin.

"To Peter Collinson—Philadelphia March 28, 1747

"Sir,

Your kind present of an electric tube, with directions for using it, has put several of us on making electrical experiments, in which we have observed some particular phenomena that we look upon to be new. I shall therefore communicate them to you in my next, though possibly they may not be new to you, as among the numbers daily employed in those experiments on your side [of]* the water, 'tis probable some one or other has hit on the same observations. For my own part, I never was before engaged in any study that so totally engrossed my attention and my time as this has lately done; for what with making experiments when I can be alone, and repeating them to my Friends and Acquaintance, who, from the novelty of the thing, come continually in crouds [sic] to see them, I have, during some months past, had little leisure for any thing else.

I am, &c.
B. FRANKLIN."

That was the first of the Collinson letters. Then on July 11th, of the same year, comes his next letter.

"Philadelphia, July 11, 1747

"Sir,

In my last I informed you that, in pursuing our electrical enquiries, we had observed some particular phenomena, which we looked upon to be new, and of which I promised to give you some account. . . ."

"The first is the wonderful effect of pointed bodies" [This had never been experimented on before. See how he does it.] "both in *drawing off* and *throwing off* the electrical fire. For example,

"Place an iron shot" [We'd call it a bullet—or rather a cannon ball. See how he describes this experiment. There isn't one teacher in a thousand that does this experiment today and does it anywhere near as well as he did it the first time it was ever done. Its quality lies in the way he handles little details. Note the way he does it to make it striking instead of merely showing a little spark, as one usually does.]

"Place an iron shot of three or four inches diameter on the mouth of a clean dry glass bottle. By a fine silken thread from the ceiling, right over the mouth of the bottle, suspend a small cork-ball, about the bigness of a marble; the thread of such a length, as that the cork-ball may rest against the side of the shot. Electrify the shot, and the ball will be repelled to the distance of four or five inches, more or less, according to the quantity of Electricity." [See, it is a beautiful lecture experiment when done as Franklin directs.] "When in this state, if you present to the shot the point of a long, slender, sharp bodkin, at six or eight inches distance, the repellency is instantly destroyed, and the cork flies to the shot. A blunt body must be brought within an inch, and draw a spark to produce the same effect. To prove that the electrical fire is *drawn off* by the point, if you take the blade of the bodkin out of the wooden handle, and fix it in a stick of sealing-wax, and then present it at the distance aforesaid, or if you bring it very near, no such effect follows"; [He is doing the experiment over again, only he is putting the bodkin on an insulator.] "but sliding one finger along the wax till you touch the blade, and the ball flies to the shot immediately. . . . If you present the point in the dark, you will see, sometimes at a foot distance and more, a light gather upon it, like that of a fire-fly, or glow-worm; the less sharp the point, the nearer you must bring it to observe the light; and at whatever distance you see the light, you may draw off the electrical fire, and destroy the repellency. . . ."

"To show that points will *throw off* as well as *draw off* the electrical fire; lay a long sharp needle upon the shot, and you cannot electrify the shot so as to make it repel the cork-ball. . . . Or fix a needle to the end of a suspended gun-barrel, or iron rod, so as to point beyond it like a little bayonet; and while it remains there, the gun-barrel, or rod, cannot by applying the tube to the other end be electrified so as to give a spark, the fire continually running out silently at the point. . . . The repellency between the cork-ball and the shot is likewise destroyed . . ." [and this is an extraordinary thing]. 3. By making a smoke about it from burning wood. 4. By candle-light, even though the candle is at a foot distance: these do it suddenly.

". . . The light of the sun thrown strongly on both cork and shot by a looking glass for a long time together, does not impair the repellency in the least. This difference between fire-light and sun-light is another thing that seems new and extraordinary to us." [He didn't understand it. Now he puts a footnote in the same letter—here is the footnote. He has been thinking it over.] "This different Effect probably did not arise from any difference in the light, but rather from the particles separated from the candle, . . ." [We call them ions now, produced by the

* Material in [ ] has been added by Dr. Millikan.

burning of the candle] "being first attracted and then repelled, carrying off the electric matter with them; . . ." [He hasn't gotten this quite right because what actually happens is, that you have ions formed at the point or near the point because of the intensity of the field rather than that the molecules themselves receive a charge and are then drawn to the shot. But it is an interesting thing that when I first studied electricity in Carhart's *Physics*, the description of the way the discharge of the points produced discharge was given exactly as Franklin here describes it. We didn't know anything about ionization in air at that time so Franklin's explanation lasted for about 200 years.]

"We had for some time been of the opinion, that the electrical fire was not created by friction, but collected, being really an element diffused among, and attracted by other matter, particularly by water and metals. We had even discovered and demonstrated its afflux to the electrical sphere, as well as its efflux, by means of little light windmill wheels made of stiff paper vanes, fixed obliquely and turning freely on fine wire axes. Also by little wheels of the same matter, but formed like water-wheels. . . . But now I need only mention some particulars not hinted in that piece, with our reasonings thereupon: though perhaps the latter might well enough be spared.

1. A person standing on wax, and rubbing the tube, and another person on wax drawing the fire," [that is, from the rubbed glass the second person touches it and gets a spark from it; both of them are on wax] "they will both of them, (provided they do not stand so as to touch one another) appear to be electrified, to a person standing on the floor; that is, he will perceive a spark on approaching each of them with his knuckle.

"2. But if the persons on wax touch one another during the exciting of the tube, neither of them will appear to be electrified.

"3. If they touch one another after exciting the tube, and drawing the fire as aforesaid, there will be a stronger spark between them than was between either of them and the person on the floor.

"4. After such strong spark, neither of them discover" [exhibit] "any electricity.

"These appearances we attempt to account for thus: We suppose, as aforesaid, that electrical fire is a common element, of which every one of the three persons abovementioned has his equal share, before any operation is begun with the tube. *A*, who stands on wax and rubs the tube, collects the electrical fire from himself into the glass; and his communication with the common stock being cut off by the wax, his body is not again immediately supply'd. *B*, (who stands on wax likewise) passing his knuckle along near the tube, receives the fire which was collected by the glass from *A*; and his communication with the common stock being likewise cut off, he retains the additional quantity received. . . . To *C*, standing on the floor, both appear to be electrified: for he having only the middle quantity of electrical fire, receives a spark upon approaching *B*, who has an over quantity; but gives one to *A*, who has an under quantity. If *A* and *B* approach to touch each other, the spark is stronger, because the difference between them is greater: After such touch there is no spark between either of them and *C*, because the electrical fire in all is reduced to the original equality. If they touch while electrifying, the equality is never destroy'd, the fire only circulating." [Here is the first description of an electrical current. Remember electrical currents weren't discovered until Volta's time, 50 years after this, but the whole of electrical current phenomena is described in that experiment, and with extraordinary care.] "Hence have arisen" [and look at the nomenclature that came into existence here at the first time that Franklin had done any electrical experimenting at all] "some new terms among us: we say *B*, (and bodies like circumstanced) is electrified *positively; A, negatively*. Or rather, *B* is electrified *plus; A, minus*. And we daily in our experiments electrify bodies *plus* or *minus*, as we think proper. . . . To electrify *plus* or *minus*," [Now this is also extraordinarily clever because he doesn't want to make any more assumptions than he needs to explain his phenomena] "no more needs to be known than this," [which is a great scientific principle which we physicists often don't use and the philosophers never use it, for they never stop when they've got enough to explain the thing they're working on. They try to get a universal out of it, and you never can get it, because we're finite beings.] "that the parts of the tube or sphere that are rubbed, do, in the instant of the friction, attract the electrical fire, and therefore take it from the thing rubbing" [the man]: "the same parts immediately, as the friction upon them ceases, are disposed to give the fire they have received, to any body that has less." [That is the description of that experiment.]

How unambiguously Franklin conceived his theory of electricity and described the most important properties of the electrical atom is shown by the following quotation of 1749, when he had had two years only of this type of experimenting, from a letter to Peter Collinson.

"1. The electrical matter consists of particles extremely subtle, since it can permeate common matter, even of densest metals, with such ease and freedom as not to receive any perceptible resistance.

"2. If anyone should doubt whether the electrical matter passes through the substance of bodies, or only over and along their surfaces, a shock from an electrified large glass jar, taken through his own body, will probably convince him." [Franklin built two Leyden jars—6 gallons each—and they were put together; the shock knocked him senseless to the floor; he had built his Leyden jars for killing turkeys, but he got a charge from them himself.]

"3. Electrical matter differs from common matter in this, that the parts of the latter mutually attract, those of the former" [those of the electricity] "mutually repel each other. Hence the appearing divergency in a stream of electrified effluvia.

"4. But though the particles of electrical matter do repel each other, they are strongly attracted by all other matter." [So, if you put this in terms of our present theories of of the atom in a neutral condition, made neutral because the positive charge on the nucleus is just balanced by the number of electrons around the outside (that's what the normal state of matter is), the matter in its normal state shows no electrical properties at all. Now, I'll go back to his original description.]

"But though the particles of electrical matter do repel each other, they are strongly attracted by all other matter." [That's why as stated, the atom when it has lost some electrons wants to get them back.]

"5. From these three things" [This is intensely penetrating] "the extreme subtilty [sic] of the electrical matter, the mutual repulsion of its parts and the strong attraction between them and other matter, arise this effect, that, when a quantity of electrical matter is applied to a mass of common matter, of any bigness or length, within our observation (which hath not already got its quantity) it is immediately and equally diffused throughout the whole.

"6. Thus common matter is a kind of spunge [sic] to the electrical fluid. And as a spunge would receive no water if the parts of water were not smaller than the pores of the spunge; and even then but slowly, if there were not a mutual attraction between those parts and the parts of the spunge; and would still imbibe it faster, if the mutual attraction among the parts of the water did not impede, some force being required to separate them; and fastest, if, instead of attraction, there were a mutual repulsion among those parts, which would act in conjunction with the attraction of the spunge. So is the case between the electrical and common matter.

"7. But in common matter there is (generally) as much of the electrical as it will contain within its substance. If more is added, it lies without upon the surface, and forms what we call an electrical atmosphere; and then the body is said to be electrified."

That's the end of the quotation. Let me quote again Franklin's phrase, "The electrical matter consists of *particles extremely* subtle." And so I say, I think the foregoing quotation clearly establishes the right of Benjamin Franklin to be considered the *discoverer* of the *atom* of *electricity*, that is, the *discoverer* of the *electron*.

The world has recently and properly celebrated the year 1947 as both the 200th anniversary of Franklin's discovery of the electron and the 50th anniversary of Sir J. J. Thompson's unambiguous establishment of the electron theory of matter. But remember that the atom of electricity itself *was discovered by Franklin, 200 years ago.* Thank you.

Evening Session

At 8:15 P.M. the final session of the day of celebration was opened in the Lecture Hall by Mr. Nalle, the President, who paid tribute to several other Philadelphia firms and institutions also observing their 125th anniversary this year. Mr. Nalle then thanked the representatives of The Electrical Association of Philadelphia, the United States Navy, and the Bell Telephone Company of Pennsylvania, for furnishing special exhibits for the Museum in honor of the occasion.

The remainder of the meeting proceeded as follows:

MR. NALLE: In celebrating our one hundred and twenty-fifth birthday we find that The Franklin Institute is to benefit by one of the great compensating devices for mitigating the yearly distress of increasing age—birthday presents. I think that I will give our Executive Vice-President and Secretary the pleasure of announcing our birthday gifts. Dr. Henry Butler Allen.

DR. ALLEN: Mr. President, Miss Florence Sibley, a good member of the Institute, and an officer of the French Legion of Honor, had the not too pleasant experience of being trapped

in the city of Verdun when it was occupied by the Germans in the last war. She won the respect and affection of the French by her good works in helping them during those sad days. So, when the people of Verdun were planning a contribution to come to America on the French "Thank you" Train, the ex-mayor of that city, President of the Association of War Prisoners of Verdun, wrote Miss Sibley for advice. He wanted her to indicate some institution in this country that would like the gift, a symbolical picture, when the gifts on the train were distributed.

Miss Sibley naturally thought of The Franklin Institute—Benjamin Franklin being a friend of France. Here it is. Mr. President, Miss Sibley is here, too, and perhaps if you ask her she will not mind briefly describing the picture to us.

MR. NALLE: Now, I think it would be most interesting to hear from Miss Sibley herself the story of this picture which we are so fortunate to have received. Just what, Miss Sibley, was your own part in bringing this picture to us?

MISS SIBLEY: Shortly before Christmas I received a letter from Monsieur Panau, President of the Association of the Prisoners of Verdun, saying that the Association was desirous of sending a gift to the "Merci Train" and that they had chosen a picture painted by one of their members, Monsieur Jeannet. Monsieur Panau at the same time asked me to suggest a society or a museum to whom to attribute their gift. I immediately thought of The Franklin Institute and got into touch with Dr. Allen who expressed much interest in the matter and said that he would be glad to accept the picture in the name of the Institute.

When the "Merci Train" arrived in Philadelphia, the car destined for Pennsylvania was detached and forwarded to Harrisburg, where the contents were exhibited during a number of weeks. After this the picture was sent to Dr. Allen, a few days before the celebration of the 125th Anniversary of the Institute.

The painting symbolizes tricolored France detached by an American tank led by the Star Spangled Banner from France covered with barbed wire. In the foreground stands one of the milestones marking the Way of Liberty leading from Normandy across France. Above the flag is a milestone of the Sacred Way running from Bar-le-Duc to Verdun and over which supplies passed during World War I. At the top of the picture rises the American monument at Montfaucon. In the center stands the Cathedral of Verdun and the Victory monument in the middle of the city. To the right is the Ossuary at Douaumont.

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The Prisoners have expressed great satisfaction at having their gift go to The Franklin Institute and Monsieur Panau has begged me to convey to Dr. Allen their grateful appreciation of his cordial reception of it along with the hope that it may prove another tie in the friendly relations between our two countries.

MR. NALLE: Thank you, Miss Sibley.

DR. ALLEN: Not long ago, Mrs. Zimbalist sent us word that she had something in her house that she thought might interest the Institute—could we set a time when I could stop in to see it. I did, and found Mr. and Mrs. Zimbalist and Mrs. Geary. We went into the dining room and there on the table was the original 1757 Will of Franklin's, written in his own hand. Mrs. Zimbalist said that she had bought it for The Franklin Institute in memory of her father. I was spellbound. Mrs. Zimbalist let me thank her, informally, but sincerely. Those thanks were reaffirmed by our Board of Managers. I now make the formal announcement to the membership of the Institute of this unique and precious gift.

MR. NALLE: Mrs. Zimbalist, would you please rise so that we may all see the person to whom we are indebted for this valuable gift, which we will cherish among our most prized possessions.

MRS. ZIMBALIST: The Institute seems happy to acquire this will, but it does not begin to be as happy as I am to present it. People ask me how I procured it, and I just say from my wonderful friend, Miss Mabel Zahn, of Sessler's Bookshop, who had endeavored to interest the Historical Society and the American Philosophical Society, but neither had the means to purchase it. I knew of no one who might be interested. I could only think of my father and his tremendous interest in Benjamin Franklin, and of course in The Franklin Institute here, so I looked the will over and there was one highlight when I came to the final paragraph.

I could not let it go. To me its thought, its great religious strain, and the nobility of the expression he used—well, I could just not get away from it. To me the wording of that final paragraph where, after making his bequests, he thanked God, using the most marvelous phrases such as: "for producing me into being" and included the other things for which he was grateful to God, but with such deep feeling that I feel it ranks with the Gettysburg Address. I could not get away from it.

I would like to speak a moment about my father. There were, of course, some similarities between Franklin and Father. They were both boys that came from Boston to Philadelphia to make their fortune—both were printers. The *Saturday Evening Post* was picked up by my father and carried on, having been founded by Franklin. I remember hearing my father say many times "Strange, strange, no memorial to Franklin in this town," and it seems fitting that it was he who led the drive to make this building possible. It became my privilege to bring to the Institute this will of Benjamin Franklin, and I feel it a personal honor to have brought it here.

MR. NALLE: And now I call on Senator George Wharton Pepper, who needs no introduction, to express, as a member of The Franklin Institute, our real appreciation to Mrs. Zimbalist.

MR. PEPPER: At The Franklin Institute interesting things are constantly happening. Seldom however, is there an event to record which is as significant as the one upon which I now wish briefly to comment. I refer, of course, to the acquisition by the Institute of the holographic will written by Dr. Franklin in 1757 and presented to us by Mary Curtis Zimbalist n memory of her distinguished father, Cyrus H. K. Curtis.

It is my pleasant duty this evening to express to her the grateful appreciation of the Institute. In so doing, I shall begin in lighter vein and perhaps even with a trace of buffoonery.

I recently came into possession of an original cartoon by Carl Rose which depicts in delightful fashion Benjamin Franklin at the court of Louis XVI, in the very act of selling to the King a subscription to the *Saturday Evening Post*. This cartoon would have delighted Mr. Curtis; and it certainly should be in the hands of his daughter, Mary Curtis Zimbalist. I beg her to accept it from me but not to open it or pass it along while I am speaking, for otherwise Rose would steal the show.

Mrs. Zimbalist's gift of Franklin's Will of 1757 has an importance which cannot be overestimated.

At your place at the dinner table each of you found a little pamphlet, which I commend to your careful study, giving in Van Doren's excellent style an account of the circumstances under which the Will was written—how Franklin was appointed agent by the Assembly of Pennsylvania to go to London to interview the Ministry in an effort to break, if possible, the deadlock between the Assembly and the Governor; how he went to New York and cooled his heels for three weeks waiting for the packet to sail; how, calming his impatience, he reflected upon his existing will and decided to make a new one; how he wrote out the whole document in his own hand and signed it on the 28th of April, 1757, and then waited six long weeks before the packet sailed.

When we look back on the Revolutionary period we are apt to think of all the actors in the revolutionary drama as having been of equal age. Not so. When this Will was written, the Marquis de Lafayette and Alexander Hamilton were just being born. The next year Admiral Nelson and the younger Pitt were born, and it was not until ten years after the date of this document that the first Napoleon and the Duke of Wellington were born. It was into a distracted world that these men were ushered and Franklin was perhaps the only stabilizing element among them all.

This Will has two characteristics. One is its extraordinary clarity, evidencing as it does a layman's grasp of all the technicalities of will-making—so that, from the technical point of view, the Will is beyond criticism. The other is that final paragraph to which Mrs. Zimbalist has called attention. I venture to think that, through the publicity which will come to it now, the document will rank very high in the list of masterpieces of English prose.

I wish it were possible to expand some thoughts that I have on this subject, but I must compress my remarks into the ten minutes allotted to me. I am going to suggest that the circumstances under which this great gift has been made enable us without too much of a flight of fancy to picture a conversation between Mrs. Zimbalist, her father, Mr. Curtis, and Benjamin Franklin. There they are—a group of extraordinary interest. They have "struck fire" at their first meeting. Indeed, they fell for one another at a glance. You and I in imagination can see them sitting together as Mrs. Zimbalist turns to Dr. Franklin and says, "Dr. Franklin, I have acquired that will of yours written in 1757 and I am presenting it to The Franklin Institute. I hope you approve?"; and Dr. Franklin, rising and bowing from the waist replies, "My dear madam, I not only approve, but I greatly appreciate this honor that you have done me"; and then she, with that spark of coquetry which is indigenous in every woman, exclaims, "Why Dr. Franklin, I am giving this to The Franklin Institute in memory of my father and not of any other man." This does not disconcert Dr. Franklin at all. Says he, "My dear lady, I am entirely content that your father should have the honor and that the Institute should have the document provided that you will bestow upon me one of your radiant smiles." And oh! what a smile she gives him! From that moment Mr. Curtis begins to feel a little *de trop*, as if it were a case for the old maxim "Two's a company—and three's a crowd"; because when Dr. Franklin found himself in the presence of a charming woman emotion took possession of him—a form of electricity in which he was much interested. However, Dr. Franklin put him at once at his ease and said, "Mr. Curtis, your daughter has honored me very greatly while honoring you; and I should like to do something of the same sort. I look forward to the time when I shall have passed on and I am anxious that the *Saturday Evening Post* should ultimately find itself in your ownership because I trust you to make it a wholesome influence in American life." Then I can hear the little chuckle that Mr. Curtis gives, as he says to Dr. Franklin, "Dr. Franklin, you honor me greatly. All I can do is to recall the incident of the negro preacher who offered his services to the Lord and said 'Oh Lord, use me as Thou wilt, even if only in an advisory capacity.'" Then all three of them laughed heartily and parted from one another with deep regret.

Such is my conception of what would have happened had these three been contemporaries. It is easy for me, at my time of life, to forget differences in age. I think that I am perhaps one of the few who was not mentioned at the dinner as contemporary with the founding of the Institute. It is easy for me to obliterate the differences in age and to think of the concurrence of people who in fact chronologically lived long apart.

It is now my pleasant function to accept this great and significant gift on behalf of the Institute—one of the pleasantest and easiest duties that a man can be called upon to perform. We give you, Mrs. Zimbalist, our profound thanks and an expression of our highest appreciation. We shall cherish this document among the most precious treasures of the Institute, and I assure you that we shall do it in such a way that these three names, separated in time but alike in merit, shall be perpetually associated with one another in our annals—your father, whom you and we delight to honor, his daughter, who has made this priceless possession possible, and Dr. Franklin, for whom our prayer is that, undying, he may long continue to be a wholesome influence in the life of America.

MR. NALLE: Thank you, Senator Pepper. Now we come to a very appropriate part of this birthday celebration, the life story of our birthday child, and I have asked Mr. James H. Robins, as one of the immediate family, a member of our own Board of Managers and a great, great grandson of the first Chairman of the Institute's Board of Managers, to give us this story. Mr. Robins!

[Ed. Note: Mr. Robins' talk, "The Story of The Franklin Institute", appeared in the June issue of the JOURNAL OF THE FRANKLIN INSTITUTE.]

At the conclusion of Mr. Robins' talk, the meeting adjourned.

MUSEUM

From the time of its inception The Franklin Institute has concerned iteslf with the education of youth and has made use of different methods adapted to the circumstances and the times. During recent years the enlargement of display facilities offered by the opening of the Museum has permitted the Institute to extend its range and to bring a knowledge of scientific developments to a wider group of people than it had hitherto reached. The current summer has witnessed a new departure and further extension of these efforts to bring science to those who are not engaged in scientific pursuits. Reaching down to a lower age level than in any earlier trial the staff of the Museum's Educational Department organized an introduction to science for very young people called "Science Adventures for Small Fry."

During the months of June and July boys and girls between the ages of eight and twelve years enjoyed ten morning field trips to the Museum. Each session covered a specific topic, such as weather, marine transportation, aviation, stars, or simple mechanisms. The subjects were presented with the aid of motion pictures, demonstrations, and science games. Where possible the young students conducted their own experiments. At the conclusion of each Adventure the young people were given souvenirs which would enable them to continue with experiments at home. Typical of these souvenirs was that accompanying the Adventure in Electricity and Magnetism, which comprised a magnet, iron filings, a compass, dry cell, wires, and other materials for simple electrical demonstrations. After the Adventure in Weather the children were given cloud charts, thermometer, and a chemical humidity indicator to assist them in home weather forecasting.

The design and execution of such a program makes heavy demands upon the ingenuity of those responsible for its presentation but, in this case, the conductor possessed the requisite qualifications for the task. Miss Clara Teaf, who is with the Division of School Extension of the Philadelphia Board of Education, was assigned the duties of conducting the Adventures. Miss Teaf had formerly served as a Museum Teacher and was, therefore, informed upon the resources and work of the Museum.

The extraordinary success of the Science Fair held in the spring of this year had demonstrated the interest taken by local school students in scientific subjects, but with a constant need for basic science understanding and the absence of science classes in primary schools, the Museum staff hopes to continue offering further Adventures for Small Fry. The response to the first series justifies consideration of conducting future series not only during the vacation period but possibly during the school year as well.

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in the JOURNAL within the next few months:

MINORSKY, N.: Energy Fluctuations in a van der Poel Oscillator.

MARIN, JOSEPH: Stress-Strain Relations in the Plastic Range for Biaxial Stresses.

DEVLIN, JAMES A., WALLACE M. MCNABB AND FRED HAZEL: Preparation of Vanadium Pentoxide Sols by Ion Exchange.

COULSON, THOMAS: The Story of Aids to Navigation.

DUBILIER, WILLIAM: Development, Design and Construction of Electrical Condensers.

FANO, ROBERT M.: Theoretical Limitations on the Broadband Matching of Arbitrary Impedances.

FANO, ROBERT M.: A Note on the Solution of Certain Approximation Problems in Network Synthesis.

JACOBSEN, LYDIK, R. L. EVALDSON AND R. S. AYRE: Response of an Elastically Non-Linear System to Transient Disturbances.

MOON, PARRY AND DOMINA EBERLE SPENCER: A Modern Approach to Dimensions.

THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

***Abstract of* Combustion Studies With the Orthicon Spectrograph.**[1]—J. T. AGNEW, R. G. FRANKLIN, R. E. BENN, A. BAZARIAN.[2] Application of the image orthicon and electronic instrumentation to spectroscopy [3] has provided increased light sensitivity, greater spectral range of response, and time resolution of a higher order than can be obtained with a moving film or plate. The instrument is ideal for studying transient or rapidly varying light sources and has already proved useful in a preliminary combustion study.

The instrument consists essentially of a television pickup tube, the RCA image orthicon, whose photo-sensitive surface is placed in the focal plane of a large-aperture spectrograph. A curve of intensity *vs.* wavelength, at any chosen instant or succession of instants, appears on the screen of an oscilloscope whose scans are synchronized with those of the orthicon. Recurrent traces are photographed with a high-speed drum camera.

A recent study has been made of the explosion in a bomb of a mixture consisting of 3.5 per cent n-heptane, 62.8 per cent oxygen, and 33.7 per cent nitrogen, by volume. This can be used as an illustration of the advantages of the orthicon assembly. Single sweep scans were

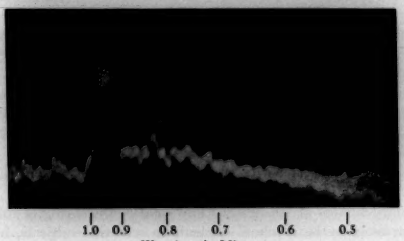

FIG. 1. Radiant energy emission during one millisecond interval from 10th to 11th millisecond.

made at the rate of one every millisecond. They were photographed on a rotating-drum camera whose speed was such that successive traces were conveniently separated. Each scan represents the integrated intensity of the preceding millisecond.

A few representative traces from the series have been reproduced in the accompanying figures. From these and the original traces, a few general observations are apparent.

The growth with time of various emission lines and bands is clearly visible. Characteristic radiation first appeared in the vicinity of 0.93 to 0.96 micron (see Fig. 1). Red and yellow bands have appeared in 15 milliseconds (Fig. 2) and strong green bands in 25 milliseconds (Fig. 3).

The appearance of the bands and lines in the order red to green and their decay in the order green to red strongly suggests the important role of temperature in these phenomena. For the mixture studied, it appeared that the temperature increased rapidly during the first part of the combustion, reached a maximum which was maintained without great change for a time, and then gradually decreased. Paralleling the temperature changes was the appearance of the red bands and lines and then the addition of the other spectral regions, the green appear-

[1] "Letter to the editor," published in May, 1949 issue of *Journal of the Optical Society of America*. Reprinted with permission of the editor.

[2] The Franklin Institute Laboratories, Philadelphia, Pa.

[3] R. E. BENN, W. S. FOOTE, AND C. T. CHASE, "The Image Orthicon in Spectroscopy," to be published.

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ing only at maximum temperature and decaying after the temperature had again fallen below that necessary to excite the region.

It might be pointed out that with a single explosion, data comprising the whole spectral region from 0.45 to 1.0 micron are obtained, and some bands are visible which might possibly escape detection if a standard photographic method were used. Also, the feature of obtaining complete spectra of the explosion at a rate of one every millisecond is unique due to the high sensitivity and storage feature of the orthicon tube.

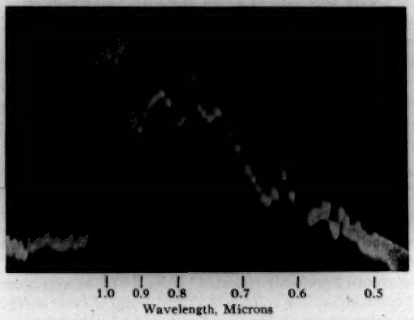

FIG. 2. Radiant energy emission during one millisecond interval from 14th to 15th millisecond.

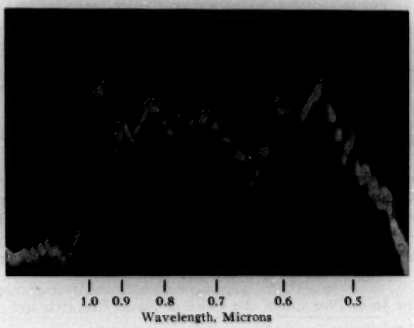

FIG. 3. Radiant energy emission during one millisecond interval from 24th to 25th millisecond.

It is also important to note that the rate of one trace per millisecond was arbitrarily chosen for this particular explosion. Faster rates could be used if the source were of shorter duration, particularly so if it were more intense. The maximum rate, using commercial components, would be approximately 15,750 traces per second, in which case the storage time would be equal to the tracing time of approximately 63 microseconds. The actual time consumed in producing the traces shown in Figs. 1–3 was 63 microseconds while the storage time was 1 millisecond.

Engravings loaned through the courtesy of the Journal of the Optical Society of America.

BARTOL RESEARCH FOUNDATION

Abstract of* Resistance of Oxide Cathode Coatings for High Values of Pulsed Emission.—W. E. DANFORTH[1] AND D. L. GOLDWATER.[1] Measurements are described of the potential variation of fine ribbon probes embedded in standard barium and strontium oxide coatings. Observations were made with 19 tubes at values of pulsed emission as high as 50 amperes/cm². Results were as follows: (a) values of resistance were found ranging from 2 to 230 ohms-cm².; (b) potential gradients were adequate to admit dielectric breakdown as a cause of sparking; (c) the curve of resistance *vs.* emission passes through a maximum and, at different temperatures, this maximum occurs at the same probe potential; (d) with BaO or mixed cathodes of higher values of resistance the resistance is largely at the interface, for low resistance coatings no observations on this matter were obtained; (e) the two best tubes as regards high emission without sparking had the lowest values of coating resistance; (f) the resistance of SrO cathodes is an order of magnitude higher than that of BaO or mixed cathodes; (g) super-position of d.c. upon pulsed emission gives a pronounced decrease of resistance.

* Paper appears in *Journal of Applied Physics*, Vol. 20, No. 2, 163–173, February, 1949.
[1] Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

Abstract of* Neutron Spectrum from N^{15} (d, n).[,1]— E. L. HUDSPETH[2] AND C. P. SWANN.[2] Gas targets of normal and of N^{15}-enriched N_2O have been bombarded with 1.2 Mev. deuterons, and the neutron spectra have been observed on photographic plates placed at 0° to the bombarding beam. Two groups previously reported [3] from N^{14} (d, n) were observed, with evidence for the production at our bombarding voltage of a third group of lower energy. Neutron groups from N^{15} (d, n) were observed at 11 Mev. and at approximately 4.5 Mev. The latter group was broader and several times as intense as the group at 11 Mev. There is evidence for a third group at 2.5 Mev., but it may belong entirely to the N^{14} reaction.

Excited states of O^{16} in the vicinity of 6.5 Mev. are well-known from studies by other experimenters of the reaction F^{19} (p, α) and from the β-decay [4] of N^{16}. Our results reveal these levels (unresolved), and no lower excited state is observed.

* Assisted by the Joint Program of ONR and AEC.
[1] Paper as yet unpublished.
[2] Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.
[3] W. E. STEPHENS, K. DJANAB, AND T. W. BONNER, *Phys. Rev.*, Vol. 52, p. 1079 (1937).
[4] H. S. SOMMERS, JR., AND R. SHERR, *Ibid.*, Vol., 69 p. 21 (1946).

***Abstract of* The Disintegration Scheme of Cerium** (141).*[,1]—C. E. MANDEVILLE[2] AND E. SHAPIRO.[2] The beta rays of Ce^{141} have a maximum energy of 0.44 Mev. An absorption curve in lead of the gamma radiation yields a quantum energy of 0.13 Mev. This gamma ray is coincident in time with the beta ray spectrum. Beta-beta coincidences are present in the disintegration of Ce^{141}, showing that the gamma ray is to some extent converted. The beta rays of Pr^{143} have a maximum energy of 0.835 Mev.

* Assisted by the Joint Program of the Office of Naval Research and the Atomic Energy Commission.
[1] Paper as yet unpublished.
[2] Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

Abstract of* Cosmic-Ray Variations at High Altitudes Resulting from Meteorological Variations.[,1]—W. F. G. SWANN[2] AND S. H. FORBES.[2] K. M. Kupferberg has called attention to latitude and seasonal variation of cosmic-ray intensity resulting from variations of the distance between the layer of mesotron production and the place of observation, which distance operates through mean-life on the cosmic-ray intensity. We have developed an expression for the percentage change of intensity at any altitude resulting from unit change in the aforesaid distance, this expression taking into account the energy distribution function and the lower limit of energy as determined by the energy necessary to penetrate the apparatus. Data supplied by the Weather Bureau show that observations extending over a single day may

experience a change of 100 meters or even more in the aforesaid distance. Our calculations show that with a change of 100 meters at an altitude of 30,000 ft. with a lower energy limit determined by 9 cm. of lead, the effect on the cosmic-ray intensity amounts to 2.3 per cent. With a lower limit determined by 18 cm. of lead, the effect is 2.1 per cent.

* Assisted by the Joint Program of ONR and AEC.

[1] Paper presented at the Cambridge, Mass., meeting of the American Physical Society, June 18, 1949.

[2] Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

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1949

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

Molecular Weights of Desoxyribonucleic Acid Polymers.—LAURA E. KREJCI, LUCILE SWEENY AND JOHN HAMBLETON. During an investigation of the enzymatic liberation of phosphorus from nucleic acid (1), estimates of molecular weight were required for a graded series of desoxyribonucleic acid polymers. The sedimentation-viscosity method (2) was utilized for this purpose because of the small amount of each polymer available.

MATERIALS AND METHODS

Desoxyribonucleic acid was isolated from calf thymus by the method of Mirsky and Pollister (3). Aliquot portions of a 0.3 per cent solution were depolymerized by the following agents:

X-rays (100,000 r)
Hydrogen peroxide (1 per cent at 40° C. for 60 min.)
Heat (60° C. for 60 min.)
Treatment in a sonic oscillator for 1, 3, 10 and 30 min., respectively
Hydrolysis in 1 *N* hydrochloric acid for 1, 1½ and 2 hr., respectively
Hydrolysis with desoxyribonucleic acid depolymerase.

The details have been described elsewhere (1).

Sedimentation velocity measurements were made in a Beams type analytical ultracentrifuge (4, 5, 6) equipped with a Philpot-Svensson optical system (7). Each polymer was examined at a concentration of about 0.25 per cent in 0.2 *N* sodium chloride solution; the samples showing least extensive depolymerization were also examined at lower concentrations. The viscosities of all solutions were measured at 30° C. in an Ostwald viscometer. The densities were measured by the method of Barbour and Hamilton (8) at the same temperature.

EXPERIMENTAL RESULTS

Sedimentation Constants. The sedimentation constants, measured at temperatures varying from 24.1 to 26.8° C., were corrected to the basis of sedimentation in water at 20° C., or to s_{20}, by use of the viscosity and density of the solutions (9). The sedimentation constants so corrected (Table I) were independent of the weight concentration of the polymer for the solutions showing most extensive depolymerization (those subjected to the action of depolymerase, acid hydrolysis, and

sonic oscillation for 10 or 30 min.). For the remaining solutions (those depolymerized by X-rays, heat, hydrogen peroxide, and sonic oscillation for 1 or 3 min.) the corrected constant increased with weight concentration; for these the lower value was used in estimating the molecular weight. The sedimentation boundaries for the acid- and enzyme-treated preparations did not completely separate from the meniscus. The heat-treated preparation showed extensive boundary spreading. The sedimentation boundaries for all other preparations were well-defined throughout the entire period of centrifuging, and showed no pronounced departures from symmetry.

TABLE I. *Molecular Weights of Desoxyribonucleic Acid Polymers.*

Depolymerizing Agent	Concn. %	Relative Viscosity	Intrinsic Viscosity	Axial Ratio	Frictional Ratio	s_{20}	M
None	0.242	3.3144	856	124	4.51	18.38	
	0.046	1.2553	852	123	4.49	10.42	691,000
Sonic 1	0.242	2.2946	593	100	4.07	12.76	
	0.048	1.2107	681	108	4.22	9.25	526,000
X-ray	0.242	2.4790	648	105	4.16	13.14	
	0.048	1.2059	666	107	4.20	9.09	509,000
H_2O_2	0.242	1.9490	477	88	3.83	10.67	
	0.048	1.1515	502	90	3.87	9.44	476,000
Heat	0.242	2.2742	587	99	4.05	16.64	
	0.121	1.3466	425	82	3.70	9.35	439,000
Sonic 3	0.242	1.7621	405	81	3.68	9.56	
	0.048	1.1373	458	86	3.78	7.72	341,000
Sonic 10	0.242	1.3672	223	57	3.13	7.15	
	0.048	1.0705	242	58	3.15	7.01	224,000
Sonic 30	0.242	1.2207	142	44	2.78	5.88	142,000
	0.048	1.0473	164	48	2.89	5.86	
Acid 1	0.242	1.0225	15.9	11.4	1.61	1.76	10,300
Acid 1½	0.242	1.0162	11.5	8.8	1.48	1.62	8,000
Acid 2	0.242	1.0162	11.5	8.8	1.48	1.10	4,500
Depolymerase	0.227	1.0183	12.9	9.7	1.53	0.82	3,000

Frictional Ratio. The frictional ratio for each solute was determined from the intrinsic viscosity by the use of the Simha equation (**10, 11**) relating intrinsic viscosity and axial ratio, and the equation of Perrin (**12**) and of Herzog, Illig and Kudar (**13**) relating axial ratio and frictional ratio.

Partial Specific Volume. For the partial specific volume the value $V = 0.58$, the average of the published values (**14, 15**), was used throughout.

Molecular Weights. The molecular weights were computed from the above values by means of the equation (2):

$$M = [6(f/f_0)\pi\eta s_{20}N(3V/4\pi N)^{1/3}/(1 - V\rho)]^{3/2}$$

in which f/f_0 represents the frictional ratio of the solute molecule, s_{20} the sedimentation constant, η the viscosity of water at 20° C., N the Avagadro number, V the partial specific volume of the solute, and ρ the density of water at 20° C.

All values are listed in Table I.

DISCUSSION

The purpose for which this graded series of nucleic acid polymers was to be used (1) necessitated a knowledge of the number average molecular weights. Ideally the sedimentation-viscosity method probably gives a weight-weight average molecular weight; for an inhomogeneous sample this is greater than the number average because it stresses the larger molecules. The procedure and approximations which were used, however, as shown below, tended to weight the data in favor of the smaller molecules, in the direction of the number average molecular weight.

For elongated molecules the random molecular orientation required by the Simha equation is realized only at very low velocity gradients. Such gradients give a high limiting value for the viscosity which is a function of the weight average of the squared axial ratios (2), and which thus stresses the largest molecules. The relatively high gradients obtained with the Ostwald viscometer minimize the influence of the larger molecules and might therefore be expected to give a value which more nearly approximates the number average when both large and small polymers are present. When the size range is narrow and the average axial ratio high, on the other hand, these gradients give too low a value for the frictional ratio.

For the solutions showing the least extensive depolymerization, the sedimentation constants corrected for the viscosity and density of the solutions increased with the weight concentration of the polymer. These are the solutions for which the viscosities measured in the Ostwald viscometer probably gave too low an estimate of the axial and frictional ratios. The use of the sedimentation constant found with the more dilute solution (0.048 per cent), instead of the still lower value which would be obtained by extrapolation to infinite dilution, should have compensated somewhat the under-evaluation of the frictional ratio, since both errors, opposite in their effect on the molecular weight, should increase with chain length.

The molecular weights listed in Table I may be subject to considerable absolute error, because hydration has been ignored, and the value

for the partial specific volume is uncertain and may vary with chain length. Relative to one another, however, they probably approximate the number average molecular weights within the limits of accuracy required by the experiments in which they were utilized. They show a striking difference in the degree of depolymerization effected by hydrolytic agents on the one hand, and by physical and oxidizing agents on the other. Under the conditions used, hydrochloric acid and desoxyribonucleic acid depolymerase produced fragments which were smaller by an entire order of magnitude than those produced by treatment with X-rays, heat, sonic vibration, or hydrogen peroxide.

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BOOK REVIEWS

PULSES AND TRANSIENTS IN COMMUNICATION CIRCUITS, by Colin Cherry. 317 pp., drawings and tables, 14 × 22 cm. London, Chapman and Hall, Ltd., 1949. Price, 32/.

This is an up-to-date book which teaches fundamentals of a particular phase of communications engineering, a many-sided profession. Although the book presents no original material, it places within its 300 pages the basic concepts of network analysis in the briefest possible form. In addition to providing a rapid summary of first principles, the author has applied the theories of transient response to subjects of recent importance such as multistage amplifiers and vestigial sideband transmission.

The book is essentially an elementary abridgement of E. A. Guillemin's "Communications Networks" to which constant reference is made. It is more enjoyable to study, and progress is more easily made than in Guillemin's books because of the omission of all but the more elementary mathematics. Excellent lists of twenty-five or thirty references at the end of each chapter not only indicate the author's familiarity with the important literature but make this a handy bibliography for the professional engineer.

The American reader will find throughout the text a number of interesting electrical terms peculiarly British. The author is a lecturer at the University of London with a background in the Research Laboratories of the General Electric Co., Ltd. He has written articles for American and British periodicals on a variety of communication subjects.

The value of the book results from the author's sorting out and applying uniform notation to the basic portions of important articles on transient analysis published in the past by key men of the communications field. Specific solutions to circuit problems are not given in sufficient detail, and the author has not been able in the space available to go deeply enough into his subject to relieve the reader of having to refer to original material. This, however, is true of most textbooks in the relation they bear to the practical solution of an actual engineering problem. The undergraduate engineer specializing in communications will benefit from the book's contents alone. In a different sense the practicing engineer will find, within the limited scope of the subjects covered, that the volume is useful as a tabular summary and reference catalogue.

C. W. HARGENS

RADIOACTIVE MEASUREMENTS WITH NUCLEAR EMULSIONS, by Herman Yagoda. 356 pages, illustrations, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1949. Price, $5.00.

A review of this is at once simplified by the fact that it need not be compared with similar books, since it is essentially the first of its kind. It is a careful recording of the research (published and otherwise) to date, dealing with the detection and study of radioactive emanations as brought into visual evidence by the photographic film or emulsion. The Geiger tube and the dramatically popular click-click of its counter have practically obscured the achievements of emulsions in popular nuclear studies and unjustifiably overshadowed their success even in the scientific mind.

All the research described in the book is based on the experimental fact that a charged radioactive emission or ionizing radiation of reasonable energy will sensitize the particles of silver halide granules to render them reducible on developing.

After describing in detail laboratory methods of preparation of radioactive samples and the use and treatment of nuclear emulsions, a large fraction of the book is devoted to the study of alpha-particle tracks. They are considered carefully with reference to their fundamental properties (for example, range), occurrence in minerals, and biology.

The beta-particle receives much less attention due to its inferior applicability to emulsion technique. Thus betas usually result in spot blackening while alphas produce discernible

tracks, as is admirably illustrated in the fascinating and numerous illustrations of this volume. Later chapters deal with gamma radiation, nuclear physics studies and cosmic rays, the latter being an especially interesting and well-illustrated section.

This book, since it contains so much experimental detail, is not conducive to continuous reading. This, perhaps, lends even more brilliance to the note on p. 231 whereon radioactive tomato slices are being discussed: "The cutting of extra-thin slices of tomatoes and other foodstuffs is a highly perfected art as practiced by restauranteurs. Details of these guild techniques have not been published."

With the many references appended alphabetically, this publication should be an indispensable handbook for workers in this field, and can provide interesting reading for the scientific curiosity seeker if he omits the laboratory details. The keynote of the book, and an admirable thought for the scientist in general, is found, perhaps, in a statement by P. Morrison quoted by Mr. Yagoda. In complimenting the cosmic ray work done at the Univeristy of Bristol, Morrison says, ". . . they use no complicated series of coincidence circuits, no microsecond timing circuits, no magnets. They employ a photographic plate, a microscope and plenty of insight, patience and skill, always the best of apparatus."

ALBERT L. MYERSON

ELEMENTS OF AERODYNAMICS OF SUPERSONIC FLOWS, by Antonio Ferri. 434 pages, illustrations, 16 × 24 cm. New York, Macmillan Co., 1949. Price, $10.00.

This book is the first of its kind in which the basic mathematical conception and development of the theory of supersonic flow are included with their aerodynamic application. Many practical aspects of the flow phenomena are presented. In general, the work covers the theoretical fundamentals of two and three dimensional flow, the application of theory to aeronautical engineering as to instruments, effusors, diffusors and wing design, and the correlation between theory and the physical phenomena.

Some highlights are chapters dealing with interaction and reflection of shock waves and expansion effusors, characteristic system for three dimensional phenomena, pressure drag of supersonic wings, and lift and induced drag of supersonic wings. One error was noted on p. 381 in which an expression is given for the total drag coefficient; it should have read as the "induced" drag coefficient.

There is an appendix listing bibliography, symbols and five tables for assistance in numerical computation.

The book is of special interest since under one cover a good background of supersonic flow theory is presented along with the current conception of application of the theory to the physical phenomena. The book seems to be well edited.

MAX W. BERG

COLLOID CHEMISTRY, by Harry Boyer Weiser. Second edition, 444 pages, illustrations, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1949. Price, $5.50.

Colloid chemistry had its beginning with the discovery of dialysis and its subsequent applications to experiment by Thomas Graham in 1860. Dr. Weiser, in this second edition, attempts to bring up to date much of the work presented in his first book. The general purpose of his book is to outline systematically the entire field of colloid chemistry, from its infancy up to the present time. The author offers the important classical work of the early colloid chemists, and presents many of the most recent theories by experts in the field. A very gratifying feature of this treatise is that Weiser presents and correlates these theories, discussing their weaknesses as well as their strong points without falling into the fault of stating as fact, that which is still only in the conjectural stage. He illustrates many of the principles and theories by showing their scientific and technical applications such as the use of phenomenon of adsorption in the function of the modern gas mask, and the purification by electrophoresis of special clays for use in the manufacture of porcelain.

The book is divided into six parts: namely, (1) Adsorption, (2) Sols, (3) Gels, (4) Emulsions and Foams, (5) Aerosols and Solid Sols, and (6) Application of Colloidal Chemical Principles

to Contact Catalysis and Dyeing. The arrangement of this edition, as the author states in his preface, follows Freundlich's "Kappilarchemie," and this approach to the subject matter seems to be most satisfactory. In an attempt to cover the entire field in one volume there must be a great deal of generalization, but the unusually complete list of references more than amply compensates for this, while at the same time provides a source of more detailed information for those who are interested in some particular phase of the subject.

The completeness of the book is evidenced by noting many of the subjects give a thorough discussion and analysis, which other authors omit or merely mention despite their obvious importance. For example: Verwey's theory of the stability of lyophobic colloids, the application of the ultracentrifuge, the work of Svedberg and Pederson, and a critical evaluation of the theory of the electrical double layer. The one criticism that could be made is that the treatment of macro-molecules is much too brief, but realizing the scope of the subject under discussion and the fact that at times only a perfunctory dissertation is possible, the author left a certain amount of deductive work to the student.

The text is profuse with equations and derivations pertinent to the phenomena under discussion. The author presupposes that the reader has a well established background in advanced mathematics, chemistry, and physics to understand thoroughly the material covered. It is quite obvious that the book is not meant to be an introductory approach to the field, but rather an exhaustive survey of classical and modern research in colloid chemistry, suitable for graduate students or for research workers. It should serve equally well as a reference book and a text book, but in either case any person interested in this branch of chemistry will find in this book a wonderful source of established work as well as the latest advances in colloid science.

DONALD H. RUSSELL

PROBABILITY THEORY FOR STATISTICAL METHODS, by F. N. David. 230 pages, 14 × 22 cm. Cambridge, University Press, 1949. Price, $3.50.

This treatment of probability theory is designed to furnish a theoretical background such as would be useful in the study of statistical methods. While it is quite plain that the justification of procedures used in statistical analysis must be based upon some conception of probability, very often this background is difficult to find or to determine. This book makes a valuable attempt to set down in a small space the ideas necessary to such a justification.

There are three important ways in which this task is undertaken. Firstly, there is to be found, in the opening chapters and from place to place throughout the book, a number of informal but extremely lucid discussions of the fundamentals of probability. Paradoxes and differences of opinion are explained and numerous references are noted for further study.

Secondly, the important theorems of probability, ranging from the binomial theorem to the study of characteristic functions, are set down, explained, and proofs given.

Thirdly, there are a large number of problems worked out in considerable detail. There is, for example, a valuable chapter on genetical applications. However, it should be noted that physical applications are not mentioned. In the main, the author has confined himself to the traditional subject matter of the theory, without venturing into mathematical physics.

The book is noteworthy for the clarity and simplicity of its style. It might serve as an illuminating introduction to the study of the theory of probability.

F. R. INNES

THEORY OF OSCILLATIONS, by A. A. Andronow and C. E. Chaikin. 358 pages, illustrations, 16 × 24 cm. Princeton, Princeton University Press, 1949. Price, $6.00.

In 1937 the authors published, in Russia, the first extensive treatment of non-linear oscillations. This volume, edited by Professor Lefschetz of Princeton University, is a somewhat condensed English language edition of that work. For many years the original publication remained little referred to, primarily because of the language barrier, but between 1944 and 1946 Dr. N. Minorsky, then of the David Taylor Model Basin, introduced the work of a whole

school of Russian mathematicians in his collected reports entitled "Introduction to Non-Linear Mechanics." This work opened new interest in this field.

Engineers often discover the limitations in the applications of the theory of linear harmonic oscillations because most practical problems are inherently those pertaining to non-linear oscillation which can be mathematically described by a set of non-linear differential equations. While the practice of linearizing equations is an expedient not to be overlooked, the existence of large deviations more often than not causes the approximate solutions to be too far removed from actual occurrence. Hence the great interest in the non-linear cases.

The original book, which developed much general theory of non-linear oscillations, has been scaled down in this volume to emphasize the numerous practical examples which appeared in the Russian version.

The basic topics considered are non-linear systems of one degree of freedom and related oscillations; in particular, the important questions of steady state and stability are repeatedly discussed.

The material is introduced through a consideration of linear systems, affording a stepping stone for the newcomer in the field. Phase space and the phase plane as applied to harmonic oscillations are introduced, for several electrical and mechanical physical systems, giving rise to the various general classes of phase space diagrams. The following three chapters are devoted to non-linear conservative and non-conservative systems and to dynamical systems described by a single differential equation of the first order. These four chapters require the least mathematical preparation, but this does not detract from the importance of the material presented. The authors have chosen to explain the methods of non-linear equations through examples met with in common engineering work; witness the following problems considered in the early part of the book: electrical and mechanical systems with negative damping; oscillating circuit with iron core; vacuum tubes with discontinuous characteristics; various kinds of relaxation oscillators; and the theory of the clock.

The advanced theories of non-linear oscillations developed primarily by Poincaré and Liapunoff are presented in the fifth and sixth chapters, which discuss dynamical systems described by two first order differential equations. Again emphasis is placed upon an investigation of the phase portraits for these systems, based upon a study of the characteristic roots for the differential equations. These results are applied in various ways in the remaining three chapters to study: discontinuous oscillations and the effects of parasitic parameters; systems with cylindrical phase surfaces, such as a pendulum with friction and an applied torque and the parallel operation of electric generators; and a quantitative investigation of non-linear systems with emphasis on the methods described by Van der Pol.

Three appendices and a bibliography of the more accessible books and papers treating the subject matter close the book.

The translators and editor have produced an excellent readable book; their efforts should not go unnoticed by the mathematicians, research engineers and scientists working with oscillatory phenomena, who should find this book extremely profitable and pleasant reading.

S. CHARP

INDENTATION HARDNESS TESTING, by Vincent E. Lysaght. 288 pp., drawings, tables, graphs, and photographic illustrations, 16 × 23.5 cm. New York, Reinhold Publishing Corp., 1949. Price, $5.50.

Interest in hardness testing can be traced back to early times when man first became aware of the different properties of the natural materials in his environment. This interest has increased greatly during the past fifty years with our growing knowledge and development of new products and new machines, and the necessity of controlling the properties of the materials utilized within certain, well-defined limits.

This excellent book will enable anyone interested in hardness testing to became familiar with the various types of equipment used and to obtain a clearer understanding of the different methods employed, since the author describes the development of numerous hardness testing machines, showing their advantages, disadvantages, limitations, and uses.

The book includes chapters on hardness concepts; on various types of hardness testers, such as the Scleroscope, Rockwell Vickers, etc.; on tests under varying conditions of temperature and of sample shape and size; on tests for both metallic and non-metallic materials; and on other related topics.

The chapter on hot hardness testing is of particular value at this time to those working with alloys used for high temperature applications, such as turbines, jet propulsion, and similar purposes.

The chapter on microhardness testing (of metals) fills a real need for more information in a field that is gaining increasing interest. Exploratory tests can be made on thin and extremely small areas, including microconstituents at high magnifications. It is possible to obtain hardness values on materials with a wide range of hardness, using appropriate loads for each material.

STUART KINGSBURY

ELECTRIC AND MAGNETIC FIELDS, by Stephen S. Attwood. Third edition, 475 pages, illustrations, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1949. Price, $5.50.

This text was written to facilitate the coordination of underclass work in mathematics, mechanics and physics with the professional work in the last two years of the undergraduate course. The author, a professor of Electrical Engineering, has prepared this text from material presented in a course in electricity and magnetism at the University of Michigan.

The text has four general subdivisions in which are discussed: (1) the electric field; (2) the magnetic field under conditions of constant permeability; (3) the ferromagnetic field; and (4) combined electric and magnetic fields.

The author elects to discuss the electric field first since he believes that studies of this field often receive too little emphasis and, moreover, that a study of this field more readily enables the student to develop the field concepts of potential, field intensity, flux density and others.

The second part of the text is so written as to emphasize current, rather than magnetic poles, as the fundamental source of the magnetic effect. In other respects the treatment of this subject is conventional.

The discussion of ferromagnetic fields is founded on a very practical basis. For example, magnetization curves and a discussion of the properties of a wide variety of ferromagnetic materials are included. Some treatment is also given to subjects involving diamagnetic and paramagnetic materials. Nearly all of the suggested problems are consistent with questions which arise in practice.

The treatment of combined electric and magnetic fields is so written as to enable the student to establish a firm foundation for later advanced studies related to the theory of propagation of electromagnetic waves

Considerable attention has been given to methods of "field mapping," and in the preparation of the illustrations, great care has been taken to insure that the shape of line of flux and equipotential surfaces are correct.

In view of the trend toward the use of the mks. system of units, this system, in rationalized form, is used throughout the text.

D. W. JENSEN

PRINCIPLES OF ELECTRICITY AND ELECTROMAGNETISM, by Gaylord P. Harnwell. Second edition, 670 pages, illustrations, 16 × 23 cm. New York, Murray-Hill Book Co., 1949. Price, $6.00.

In this second edition of Dr. Harnwell's book on basic and fundamental phenomena in electricity and magnetism, the author has primarily added and revised those sections of the original work which bear upon the tremendous advances in electronics, atomic and nuclear physics which occurred in the past decade. Continuing emphasis is placed upon fundamentals and basic physical theories and laws, especially from the point of view of the experimental

physicist rather than that of the electrical engineer, although in many respects such distinction is rather artificial for a book of this kind.

The text is written for the advanced undergraduate student in either physics or electrical engineering who has had previous courses in introductory physics including heat and mechanics, differential and integral calculus, elementary differential equations, and the vector notation. The subject matter, drawn from classical physics and advanced electrical engineering, requires such background preparation in order for the reader to understand those physical phenomena which can best be expressed in terms of mathematical relationships.

The classical order of presentation of the subject matter is utilized for the most part, albeit the classical viewpoint has in many places given way to modern theoretical thought, especially where it was found necessary to integrate the new and recent developments and discoveries with the older concepts and practices.

The first subject considered is electrostatics; the study of charge configurations, their resultant mechanical forces and energy; the elementary vector concepts; and the physical characteristics of dielectrics and conductors.

The electric effects of charges in motion, non-magnetic in nature, are introduced in a chapter on direct current circuits, this being followed by chapters devoted to: non-ohmic circuit elements and alternating currents; chemical, thermal and photoelastic effects; thermionic vacuum tubes; and the conduction of electricity in gases. These phenomena, usually not so fully covered in a general textbook, are treated in an extensive manner, the descriptive illustrations being drawn from current applications of modern circuit theory and developments.

Magnetic phenomena are introduced by considering the electromagnetic effects of moving charges and the electromagnetic effects of charging electric currents. This is followed by a discussion of the magnetic properties of matter, a subject which usually precedes the former material. The remainder of the book is devoted to subjects of prime interest to the electrical engineer and of considerable interest to anyone engaged in physical research and communications. These include: electromagnetic machinery; linear constant parameter filters, and transmission lines; vacuum tube circuits; and electromagnetic radiation. These latter chapters place some emphasis on ultra-high frequency techniques and phenomena, a natural extension from the earlier edition. The material on radiation is based, of course, upon appropriate solutions of Maxwell's equations for dielectric and conducting media, illustrated by their application to wave guides and antennae.

Throughout the copiously illustrated book appear numerous references to the current literature. The problems found at the end of each chapter serve to test the student's understanding of the basic principles of the subject matter; in many cases they have been chosen to illustrate applications of a very practical industrial or research nature. In addition to its classroom application, the book is recommended as a basic reference text for practicing electrical engineers and physicists who desire a thorough review of this subject matter from the physicist's point of view.

S. CHARP

BOOK NOTES

STEEL AND ITS HEAT TREATMENT. VOLUME III. ENGINEERING AND SPECIAL-PURPOSE STEELS, by D. K. Bullens and The Metallurgical Staff of the Battelle Memorial Institute. Fifth edition, 606 pages, illustrations, diagrams and tables, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1949. Price, $7.50.

This present third volume of Bullens covers the subject of Engineering and Special-Purpose Steels, which was treated in Volume 2 of the fourth edition. The considerable increase of knowledge of the subject in the last decade has necessitated a quite thorough rewriting and enlargement of the text. Particular attention has been paid to the importance of hardenability data and the realization that composition in an alloy constructional steel is of importance only as it affects structure. The possibilities of using alternate steels are indicated.

The main sections are: Engineering alloy steels; constructional alloy steels for heat treating; special steels. As a correlated presentation of the known facts about the important alloy and special steels, this volume continues to serve a useful function.

ELECTRON TUBES. VOLUMES I AND II, 1935 TO 1948 (The Ninth and Tenth Volumes of the *RCA Technical Book Series*), edited by A. N. Goldsmith and others. 475, 454 pages, illustrations, 15 × 22 cm. Princeton, *RCA Review*, 1949. Price, $2.50 per volume.

The present two volumes are the ninth and tenth in the RCA Technical Book Series which reprint significant contributions by RCA authors in various fields of electronics. These are the first which have been devoted exclusively to tubes, Volume I covering the period 1935–1941, while Volume II brings the record through 1948.

Following the pattern set in earlier volumes, some papers are presented in full, while others are given only in a summary. Each volume is divided into four sections: general; transmitting; receiving; and special. In addition to the articles reprinted, a full bibliography of all papers on tubes by RCA authors has been included, which, for the sake of completeness, notes those articles on the applications of tubes which are considered in other volumes of the series.

The volumes will serve as a useful compilation of the many contributions made to electron tube research by RCA engineers.

ANNALES DES TRAVAUX PUBLICS DE BELGIQUE. Numero jubilaire 1843–1948. 213 pages, illustrations, 24 × 31 cm. Brussels, G.I.G., 1949. No price.

In recognition of its hundredth year of publication, the *Annales des Travaux Publics de Belgique*, established in 1843, has just issued a special jubilee number. Because of its function as the organ of the Belgian Ministry of Public Works, the *Annales* offers in this number several historical articles on the various types of public works executed in Belgium since 1830, as well as other subjects in the field of civil engineering. After an introductory section outlining the origin and purpose of the publication, the first section is devoted to roads, with three articles. Of these, one is devoted to planting along the highways, discussing briefly the various problems encountered and the need for planning. Canals are treated at some length and the accompanying maps depict graphically the great development since 1914. Buildings and bridges are also treated in separate chapters.

Louis Baes has written a summary article on the resistance of materials, the theory of elasticity and of the plasticity of solid bodies. Although this has been treated in limited scope, it makes ample reference to the literature and should prove useful. Other articles consider such varied topics as research laboratories, developments in metal construction, railroad bridges, local rapid transit, metallurgy and water works.

With many illustrations this is a worthy issue to note the hundredth anniversary of the *Annales*, and it will prove valuable as a reference source on the history of engineering in Belgium.

TABLES OF BESSEL FUNCTIONS OF FRACTIONAL ORDER, prepared by the Computation Laboratory of the National Applied Mathematics Laboratories, National Bureau of Standards. Volume II. 365 pages, tables, 20 × 27 cm. New York, Columbia University Press, 1949. Price, $10.00.

The JOURNAL for December 1948 carried a note on the appearance of Volume I of these tables. The present volume comprises tables for Bessel functions of fractional order: $I_\nu(x)$ for $\nu = \pm \frac{1}{4}, \pm \frac{1}{3}, \pm \frac{2}{3}, \pm \frac{3}{4}$. The value and usefulness of tables such as these needs no further comment.

BIBLIOGRAPHY ON SPRAYS, by Kalman J. DeJuhasz. 98 pages, 21 × 28 cm. New York, Texas Company, Refining Department, Technical and Research Division, 1948. No price.

The recent development in gas turbines and jet engines has encouraged the author to bring up-to-date an earlier bibliography on liquid jets, sprays and nozzles, published in 1932.

In the present listing, in addition to the oil engine applications of the earlier list, other industrial applications of sprays have been noted, as well as such borderline subjects as dusts, powders.

The bibliography itself was prepared in connection with two research projects, one for the U. S. Navy Department, Bureau of Ordnance, and the other for The Texas Company.

The entries are arranged alphabetically by author, and generally full bibliographical data are given, with the titles of foreign entries both in the original language and translated into English. Abstracts are included. About ten per cent of the entries would seem to be cited without having been seen. It is to be hoped that in undertaking a revision, more of these will be examined, since a considerable part of those cited would seem to be relatively available. A subject index is included.

The method of reproduction unfortunately leaves something to be desired, since some entries run off the bottom of the page. Despite these deficiencies, the bibliography presents evidence of a quite extensive coverage of the literature which will prove useful and the author should be encouraged in his plans to keep it up-to-date.

TIN, ITS MINING, PRODUCTION, TECHNOLOGY AND APPLICATIONS, by C. L. Mantell. Second edition, 573 pages, illustrations, tables, maps, 15 × 23 cm. New York, Reinhold Publishing Corp., 1949. Price, $10.00.

In revising this work first published twenty years ago, the author has amplified the text by nearly a half. The same general arrangement has been followed, with the addition of a chapter on electrolytic tin plate and the division of the chapter on alloys into three chapters. In these the greater knowledge available on the different tin alloy systems has been reviewed.

German practice has been more extensively covered on the basis of a German translation of the first edition and the information gathered by the technical teams who studied German metallurgy after World War II. In its expanded form, "Tin" remains an outstanding work in its field.

INSTALLATION AND SERVICING OF LOW POWER PUBLIC ADDRESS SYSTEMS, by John F. Rider. 204 pages, illustrations, 14 × 19 cm. New York, John F. Rider Publisher, Inc., 1949. Price, $1.89.

A practical book on low power public address systems, limited primarily to those up to and including 50 watts. Microphones and phonograph pickups, amplifiers, and loudspeakers are treated at some length in separate chapters. Suggestions are given for the installation of public address systems under varying conditions and a concluding chapter discusses the problem of servicing.

CURRENT TOPICS

The Spectra Direct Reading Color Temperature Meter.—The SPECTRA Direct Reading Color Temperature Meter made by Photo Research Corporation, San Fernando, California, is the first instrument offered to the general public for measuring the exact color of a source of illumination. It operates photo-electrically and is therefore independent of individual eyesight and personal judgment.

Everyone is familiar with the fact that the appearance of objects depends greatly upon the illumination which falls on them. Even an unobservant person cannot fail to note the difference between objects seen under sunlight and candlelight, and every woman knows that colors which match under tungsten light do not match in daylight.

These, however, are large differences of which almost everyone is aware. In recent years, the growing importance of color photography, and the increasing need of precise color matching in many fields, has made it necessary to deal with much smaller differences—differences which the human eye is totally unable to perceive because of its ability to adapt itself to them, yet which can seriously impair the correctness of color matching or of a color photograph.

Practically no light source in common use furnishes light of constant, known color. Sunlight varies in color with the time of day, the season, the weather, the altitude, and many other factors. Tungsten light is somewhat more constant, but serious variations occur which depend on the wattage of the lamp, its age, the voltage at the lamp (which varies widely in most communities) and other influences.

For a decade or more there has been a need for an instrument which would measure the color of a source of illumination in a precise way, so that suitable corrective measures might be applied. That need has finally been met in the SPECTRA. The SPECTRA is simple in principle, and no special knowledge or skill is required for its operation.

In order to measure the color of illumination, we must have some sort of units in which to measure it. Fortunately, such a scale of measurement already exists in the laboratory. It is known as Color Temperature. It is not necessary to understand Color Temperature in order to use the SPECTRA, but for those who are interested in understanding how it operates, here is a brief explanation:

The Color Temperature of a light source is the Kelvin temperature to which a black body would have to be heated in order to give off light of the same color. The Kelvin temperature is measured in degrees Centigrade above Absolute Zero.

When we know the Color Temperature of a light source, we can say exactly how much red, yellow, green, blue and violet is contained in the illumination. Similarly, if we know how much of these colors is in the light, we can compute the Color Temperature.

Fortunately, it is not necessary to follow such a complicated procedure. It is sufficient to measure the amount of any two colors in the light source, and the ratio between those two colors will correspond to one Color Temperature, and one only. This is what is done in the SPECTRA.

First, the SPECTRA is pointed at the light source which we wish to measure. It is now measuring the red content of the light. We adjust a ring so as to bring the needle on the scale to a red mark. This adjusts our red reading to a standard value. Then we pull the trigger on the SPECTRA. This moves the red filter out of the way and swings a blue filter in front of the light sensitive cell. With the trigger held back, the needle now tells us on the scale the exact Color Temperature of the light source. That is all there is to it.

If we are taking a color photograph on Daylight Type film, the light should be 5900 K. For Type A or Photoflood film, it should be 3400 K., and for Type B or Tungsten, 3200 K. If the SPECTRA shows a departure from the correct figure, corrective measures must be taken, such as the use of filters, as explained in the directions furnished with the meter.

An important feature of the SPECTRA is the Spectrasphere, a diffusing hemisphere which is placed over the instrument when light of mixed character is to be measured. Out of doors, for example, direct sunlight and light coming from the sky are not of the same color. Indoors, several lamps may be in use which are not of exactly the same color. The Spectrasphere mixes and averages up the various light sources, and provides a figure which is the best guide to the most favorable results.

Farm Alcohol Makes Low-Octane Motor Fuel Equal to Regular Gasoline.—On two recent trips of nearly 1000 miles each, a U. S. Department of Agriculture test truck ran successfully on relatively inexpensive low-octane gasoline fortified by periodic injections of alcohol and water. Results of these long-distance road trials, according to the Department's Bureau of Agricultural and Industrial Chemistry, show how using alcohol in motor vehicles can help conserve petroleum and provide a potentially vast new market for surplus grains. The tests were made as part of the motor-fuels work financed under the Research and Marketing Act.

Bureau researchers report that in the first trial the truck operated as well on 58-octane gasoline plus alcohol-water injection as it would on regular gasoline, which has an octane rating of 74 or better. The alcohol-water mixture (85 per cent alcohol, 15 per cent water) was injected automatically into the truck's carburetor when the engine was under heavy load, as in climbing hills, accelerating in traffic, or passing other vehicles. This enabled the engine to give knock-free performance even with the low-octane gasoline.

For the second trial run the engine of the truck was equipped with a high compression head (8.25-to-1 compression ratio). This made it necessary to supply the engine with fuel having an effective octane rating of at least 85. On this trip 74-octane gasoline plus alcohol-water injection was used satisfactorily.

Because of the tremendous consumption of motor fuels—more than 80 million gallons a day—general adoption of alcohol-water injection could open up a wide new outlet for surplus grains and other agricultural commodities. Alcohol can be made from a variety of these products. The usual method is

by fermentation of wheat, corn, or other starchy crops, and scientists at the Peoria laboratory are working to lower the cost of alcohol and to increase the value of feed byproducts produced by this process. They are also developing methods for converting corncobs and other farm residues to alcohol.

The Laboratory's researchers also point out the potential importance of alcohol-water injection in extending the country's supplies of petroleum. Alcohol is equivalent to 100-octane fuel, and it can be used to increase the effective octane rating—or anti-knock quality—of gasoline. It thus makes possible wider use of low-octane fuels, which are cheaper and can be produced from petroleum in greater quantity than high-octane gasoline.

New ACF-Talgo Train (*Diesel Power*, Vol. XXVII, No. 6).—A unique train, first to be built in America based on the Spanish "Patentes Talgo," has been completed by the American Car and Foundry Company for testing and demonstration. Designed by ACF and Talgo engineers and constructed at the Berwick, Pa., and Wilmington, Del., shops, this revolutionary streamliner is one of three such trains, the other two being destined for revenue service in Spain.

The "ACF-Talgo" train represents entirely different concepts in railroad passenger car construction. A comparison with streamline equipment on the railroads today shows the ACF-Talgo to have floors 2 ft. 9 in. lower, a weight reduction of nearly 75 per cent due to both its design and all-aluminum construction and an overall height lower by almost four feet. Completely new throughout, the train presents a very dramatic appearance due to its extremely low center of gravity. Moreover, it is equipped and decorated in keeping with its modern design. The name "Talgo" is derived from Tren (train) Articulado (jointed) Ligero (light) Goicoechea (the inventor) and Oriol (the man backing the train).

Each Talgo for Spain will consist of a diesel-electric locomotive, a baggage unit, and three coaches, the last of which features an observation lounge. The over-all length of the train is approximately 370 ft. and is for 5 ft., 6 in. gauge track. The design is unique in that a coach consists of four articulated passenger units and one equipment unit, each of which has only one pair of wheels in the rear. The front is supported by a special coupling arrangement on the unit ahead of it, while the first unit is supported by the locomotive.

Entrance to the coaches is gained through the equipment unit which is in the center of each coach. These equipment units contain various functional items such as air-conditioning equipment, control lockers, washrooms, and kitchenettes for serving light meals.

Each coach is 100 ft. long and seats 64 passengers, 16 in each passenger unit. The coach containing the observation lounge is 7 ft. longer. The entire train seats 176 passengers with 16 additional seats in the observation lounge.

An experimental train of this type has undergone successful tests in Spain. ACF, realizing that the ideas embodied in the Spanish train presented a challenge to American industry, entered into a partnership agreement with "Patentes Talgo" which included exclusive manufacturing rights and sales representation in the United States and Canada.

The train for experimental purposes is of identical design to those destined for Spain with the exception of length and gauge, the latter being generally 4 ft.

8½ in. in the Western hemisphere. It consists at this time of only a diesel-electric locomotive, a baggage unit and a coach of five units, one of them being for equipment and another serving as an observation lounge. The train is 168 ft. long or only approximately one-third of its eventual length.

This unit has been planned to show just one of the many possibilities of interior design. Wide-vision windows, a 42-in. seat spacing, wardrobes and luggage storage facilities in each coach, individual ash trays at each seat, kitchenettes to provide meal service at the seats and an observation end from which passengers have extra-wide visibility are some of the ideas which have been incorporated. It can be adapted to both long and short hauls, coach or sleeper service, depending on the requirements of individual railroads and its passenger carrying capacity increased or decreased to suit the density of traffic.

Obviously, the Talgo is a complete break with tradition in the construction of railway equipment. It will be interesting to watch its progress. Many advantages are offered to the railroad industry that heretofore have never been available.

Engineered for rapid and economical production and incorporating such features as the use of standard automotive type diesel engines for power, elimination of approximately 75 per cent of the dead weight and facility of maintenance and servicing, these units should make an attractive, economical package.

Rocket-Jet Airplane (*Mechanical Engineering*, Vol. 71, No. 7).—What is believed to be one of the first flights ever attempted under dual rocket and jet power was made recently by the D-558-2 Skyrocket, the Navy Department's Bureau of Aeronautics revealed. The research craft took off from the desert runways of Muroc, Calif., test base.

After exhausting its rocket fuel, the Navy test ship continued upon a routine research flight and landed under turbojet power.

For the past year the Douglas-built explorer has made numerous routine research flights powered by its turbojet while awaiting final development of the jet-rocket engine recently installed.

Designed and developed for the Navy by Douglas Aircraft Company, Inc., in cooperation with the National Advisory Committee for Aeronautics, the Skyrocket is obtaining valuable knowledge on advanced power plants and speeds near the sonic range of flight.

The D-558-2 Skyrocket is the advanced sequel to the Navy's D-558 Skystreak, straight-winged red jet which in the course of its research investigations broke the world speed record twice within five days in August, 1947.

Though of advanced aerodynamic design and incorporating the latest power plants, the Skyrocket performs as a conventional aircraft taking off and landing under its own power.